AMPUTATIONS

Hugh Owen Thomas, a pioneer in orthopædic surgery
(1834–1891)

[*Frontispiece*

AMPUTATIONS

BY

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He is a good surgeon who can amputate a limb
but he is a better surgeon who can save a limb.
SIR ASTLEY COOPER.

1954

WILLIAM HEINEMANN MEDICAL BOOKS LTD

LONDON

First Published 1954

Printed in Great Britain by
The Whitefriars Press Ltd., London and Tonbridge

FOREWORD

Mr Leon Gillis has brought together in the form of a comprehensive text book both the fruits of his own intensive experience and the significant contributions of surgeons in Great Britain and other countries in the special field of amputation technique It is fitting that such a work should come from Queen Mary s Hospital Roehampton a centre which has earned a world wide reputation In a second volume yet to come Mr Gillis proposes to deal with the subject of artificial limbs and thus to provide an authoritative work of reference which will be welcomed by surgeons far and wide

HARRY PLATT

PREFACE

AMPUTATIONS are the unavoidable end results of disease and injury and the operative word therefore should be unavoidable Although their history is as old as surgery itself great gains in the knowledge about amputations due to trauma resulted from the experiences of the two World Wars

In the work that follows we have endeavoured to apply the lessons thus learnt Firstly an attempt has been made to recognize the conditions requiring operation and then to decide when where and how to operate Later on the importance of rehabilitation is stressed followed by a consideration of the best prosthesis and how the patient can be trained to use that prosthesis so that he may resume normal life and normal work.

More space than usual in a textbook covering this field has been devoted to cases of vascular disease for in the earlier stages measures to improve the general circulation and increase the blood flow to a threatened limb may succeed in avoiding amputation In less fortunate cases judgment and experience are required to decide when amputation has become necessary and the level at which it should be performed. The views here expressed are based on experience gained at Roehampton and will we believe meet with the approval of the majority of general as well as orthopaedic surgeons

A chapter on the management of congenital absence of limbs and amputations in children has been included, and it is hoped this will be of guidance to those not versed in these problems

For many years amputations have been performed in accordance with principles laid down in textbooks as a result of the experience of generations of surgeons Some of these have stood the test of time but we have been so bold as to question others and to suggest changes in some of the traditional techniques which more recent experience and more modern prostheses have made possible Here the general surgeon can learn much from the limb-surgeon and the technicians who will be responsible for fitting the correct type of artificial limb following the appropriate operation for it is the limb-surgeon who is able from his experience of many amputations to assess the type of stump that will be most satisfactory in any particular case and advise on what prosthesis is the more likely to enable the patient to lead a comfortable and useful life afterwards

As the result of the study of thousands of amputees following the 1914–18 War an immense amount of knowledge has been accumulated in recent years concerning amputation procedures and the fitting of artificial limbs further enhanced by the experience gained in the 1939–45 War by limb surgeons of the Ministry of Pensions It is now possible to decide in any individual case what is the best type of stump from a limb wearing aspect that is a stump that will not require frequent treatment or the bugbear of subsequent re amputation and one which will permit the patient to wear a comfortable socket

Manufacturers of artificial limbs have been supplying their products and recommending for years the type of limb which in their past experience has been found the most suitable It has been discovered however that the surgeon and limb-maker have often been working

in watertight compartments the surgeon designing operations which although surgically excellent have not in the experience of the technician always been capable of ensuring the best prosthetic results What is now required is closer collaboration between the two It is hoped this work will be conducive to that end.

L. G

May 1954

ACKNOWLEDGEMENTS

In the preparation of this book and its sequel 'Artificial Limbs' I owe a great debt to the Directors General of the late Ministry of Pensions in particular the two last Sir Francis Prideaux C B E and Sir Frederick Rees C B E M C for the encouragement I have received from them in my work and for the material they made available to me I gladly acknowledge also my debt to many other workers in the field and in particular I would like to mention that due to the late F Muirhead Little F R C S

It has been my endeavour to set out some of the surgical teaching of my own Universities Witwatersrand and Liverpool and to add to it what I have learned from the Edinburgh and London schools of thought I am particularly conscious of my indebtedness to what might now be called the School of Amputations at Roehampton where it has been my good fortune to work for so many years Visits to the United States of America and many European countries have added to my understanding of the problems involved and I have used the literature of these countries whenever pertinent I have also quoted sometimes verbatim with permission from my original articles in the *Annals of the Royal College of Surgeons* the *Journal of Bone and Joint Surgery* the *British Medical Journal* and the *Proceedings of the Royal Society of Medicine*

For much advice and helpful criticisms I am indebted to many surgeons including Mr St John Dudley Buxton F R C S Sir Hugh Griffiths C.B E F R C S Mr S Pappworth M Ch (Orth.) Professor T Pomfret Kilner C B E F.R C S Professor A K. Henry M Ch F R C S Mr A Dickson Wright M.S F R C S Mr S S Rose F.R C S and Mr H G Korvin M D F R C S The last named has been untiring in helping me with the proofs of this book. Dr W A Low has given me many useful hints for the chapter on Anæsthetics

I also acknowledge the help given me by the Medical Superintendent of Queen Mary's Hospital Roehampton Dr E C Murphy

My Registrars have been of great assistance to me and in particular I wish to mention Mr K Dalliwall F R C S Dr I McNicol Smith Dr M Vitali and Dr A E Wheatley Dr R Ascott of Queen Mary's Hospital Roehampton, has helped me with the Plastic Surgery section of this book while Dr J Kohn of the Pathology Department in the same hospital has given me much assistance with the bacteriology The co-operation of the Radiological Department of Queen Mary's Hospital Roehampton has been continuous and in particular I would like to offer my thanks to Dr H. M Harper who has helped me with the chapter on Radiography and has worked out the details over a period of years I wish to thank also Dr J R Seymour Reynolds for his help and criticism The Physiotherapy Department at Roehampton under the charge of Miss D M Dodd has carried out much valuable work in connection with the preparation of stumps and has generally been of the greatest assistance to me as has the Occupational Therapy Department under the charge of Miss A. Mendez. Miss N Mosgrave has been most helpful in the physical rehabilitation of patients

Miss Dorothy Channing Smith B.A. with untiring perseverance has brought together

the literature on amputations and Mr A J Bride B Sc has given great help with the editing To my Secretaries—especially Miss M. Body and Mrs V Bettles—I offer my thanks for their patience and perseverance

My colleagues at Queen Mary s Hospital, Roehampton and at the Limb Fitting Centre have over a period of many years referred cases to me and have been most helpful with their advice and I have availed myself of some of their clinical material and photograph I would make acknowledgement to Mr P Metcalfe C V O R D I. for the skill accuracy and beauty of his drawings and also to Mr M. J Bunn who has so willingly placed his artistic ability at my disposal.

Without the interest and help I have received from Messrs. Hugh Steeper Ltd Artificial Arm Manufacturers and Messrs J E Hanger & Co Ltd. Artificial Leg Manufacturers my task would have been more difficult

To my publishers Mr J Johnston Abraham and Mr Owen R Evans of William Heinemann Medical Books Ltd. I am indebted for much assistance in the construction of the work and for the helpful advice they have given me at all times

Last but not least I would mention my wife for her understanding and forbearance and also for her literary help throughout the years during which I have been compiling this book.

It is difficult to write a list of acknowledgements—it is even more difficult to make that list complete So many have helped during the long period of preparation that some are almost sure to have been un named May I end therefore by saying that to all who have made this book possible I acknowledge a debt which cannot be repaid

114 Harley Street
London W 1

Leon Gillis

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CHAPTER I

HISTORY OF AMPUTATIONS AND PROSTHESES

Amputation: one of the meanest and yet one of the greatest operations in surgery: mean when resorted to where better may be done—great as the only step to give comfort and prolong life

SIR WM FERGUSSON 1865

A KNOWLEDGE of this ancient aspect of surgery is not only interesting but also instructive and a sketch of the great eras of progress in the methods of amputation and prosthetics may appropriately preface this book

In surgical language the term amputation (derived from the Latin *amputatio* meaning a cutting around) is applied to all cases of removal of limbs or portions of limbs by the knife, although more accurately it should be restricted to those cases in which a limb is removed in the continuity of bone. Removal at a joint is called disarticulation The term amputation is also applied to the removal of any projecting organ such as a breast or testicle

Amputation was practised by primitive peoples and some archæologists think it has been in use at least since Neolithic times Neolithic stone knives and saws of stone and bone have been found and the presence in the skeletons of the period of what look like amputated bone stumps suggests that this may have been one of the uses of these instruments

The murals of La Tène and elsewhere depict many hands with fingers amputated while some ancient Peruvian pottery shows the figure of a man with a leg amputated at the tibiotarsal junction holding in his right hand a pointed cap to be adjusted to the stump of the leg

Whatever the intent of such amputations for magic ritual sacrifice punishment or the cure of disease their advent created not only the need of a substitute but also made the ancient operator seek their corollary instruments Saws surgical knives and, later artery forceps and ligatures became necessary

Albucasis who was a capable Muslim surgeon towards the end of the eleventh century wrote a surgical treatise which contains this passage —

> When gangrene of the lower arms or legs does not yield to medication one should amputate to prevent it extending above the elbow or knee before it becomes fatal The limb should be tightly bound above and below the line of severance, while an assistant pulls upwards on the upper bandage to retract the skin and flesh One should make a circular incision down to the bone insert linen pads on both sides to prevent ulceration then cut or saw through the bone If hemorrhage occurs during the operation cauterize promptly or apply some hæmostatic powder before proceeding apply a suitable dressing and tend until cured

The Saw There is evidence from specimens which have been excavated in various

parts of the world that the saw has been known to man from the Neolithic period more than 6 000 years ago this period which marks the beginning of the greatest step in the evolution of human culture The idea of a toothed implement for cutting bone or wood may have been suggested to him by such natural objects as the sawfish with its sharp projections or the finely serrated teeth of the shark.

Ovid ascribes the origin of the saw to Talos, the nephew of Daedalus who was supposed to have conceived the idea from the jaw of a serpent with which he found he was able to cut a piece of wood But whether there is any substance in this mythological story or not saws with blades of finely flaked flint with serrated edges have been discovered in the lake dwellings in Switzerland and also in Egypt dating from at least 2700 B C

A specimen mounted in wood with a handle now in the British Museum is said to be of predynastic period and shows the tool as used by the Egyptians over 4 000

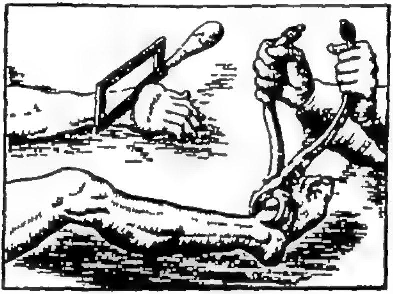

FIG 1 Hand and foot amputation. How Johannes Scultetus (1595–1645) coped with hand and foot amputations is shown in his " Armamentarium Chirurgicum. Before the hand was amputated the surgeon cut through the soft tissue to the bone with a sickle-like knife, so that removal of the hand could be accomplished with one cut of the sharp saw A tong like instrument was used in the amputation of gangrenous feet.

(Scultetus Armamentarium Chirurgicum 1666.

years ago The flint blade was superseded by metal in later times and the saw represented in a painting at Thebes, about 1500 B C depicts the Egyptian carpenter using a tool similar in shape to that employed to-day

In ancient Greece saw blades of copper were first employed These were followed by bronze which is harder and more durable

A century before the Christian era the Romans used blades of iron and crude steel The saws employed by the Romans were chiefly of the tenon and frame pattern type as is shown by a carving on stone now in the British Museum

The Knife. Celsus, in the first century A.D describes amputation through healthy tissue using knife and saw From Roman remains of this period it is probable that the knife he used was a large straight scalpel with bronze blade and iron handle Various models of straight knives existed through the centuries sometimes with the cutting edge concave sometimes convex.

In the sixteenth century Ambroise Paré who as a military surgeon had considerable experience of amputation in the field designed two types of knife—an incision knife with a thin concave curved blade and a crooked knife with a sickle shaped blade cutting on the inside for dismembering This curved shape remained in favour with minor modifications e.g., Sharp's knife which had a cutting edge on both sides until in 1788 Loder re introduced the straight blade and was followed by Bell Savigny and Sir Astley Cooper while Lisfranc devised a straight knife with a double edge. In the mid nineteenth century Liston who achieved a high degree of perfection in the art of amputation preferred a straight knife with a dagger pointed blade 12 to 14 in long well suited for amputation by the circular tour de maître employed in those days

Artery Forceps Before the invention or at least before the general introduction of the ligature and the tourniquet the great barrier to all improvement in operative technique

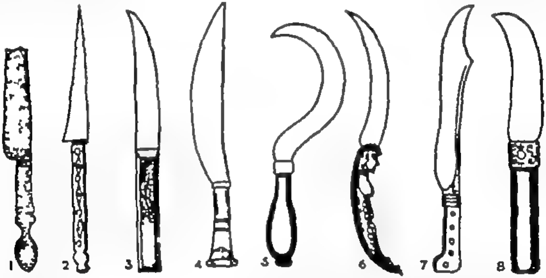

FIG 2. Amputation knives: 1 Roman; 2 Albucasis 3 Wryghtson, 1350; 4, Knife of the fifteenth century; 5 Paré's crooked knife; 6 Paré's incision knife 7 Vesalius, c. 1550 8 Guillemeau 1594.

[*From Thompson The History and Evolution of Surgical Instruments. Henry Schuman 1942. Reproduced Pictures Essays on Historical Medicine 1946.*

was the impossibility of checking hæmorrhage both during the operation and after its conclusion Many surgeons would not amputate at all; others only through gangrenous parts others more bold only at the confines of parts in which gangrene had been artificially induced by tight ligatures

It would seem logical that artery forceps should have followed Harvey's discovery of the circulation of the blood, but actually they preceded it Forceps similar to dissecting forceps, as we know them, including the tongs pattern were used for epilation by the ladies of Ur (3200 B C) and in the early Egyptian Greek and Roman civilizations Aristophanes and other dramatists were unable to resist them as a subject for doubtful jokes They are also found among the remains of the Bronze Age (Hallstadt 800 B C) in Europe where men of that period also used them for hair trimming The mummy preparers of Egypt had similar forceps and the golden lamp tongs mentioned in the Bible for use in the Temple were probably of a similar design

The collar-stud catch in a central slot and ring sliding over the forceps to keep the points together was designed in the Hallstadt* period (*circa* 800–400 B C) and was

* Hallstadt is a village in Austria.

well known and freely used by the Romans in spring forceps The convenience of a catch to hold the forceps points together while leaving the hands of the surgeon free for tying the ligature seems obvious but this great improvement in design was generally ignored The spring ratchet-catch apparently borrowed from the watchmaker s ratchet was not invented until the beginning of the nineteenth century Charrière made the first one

Nothing new had been achieved in the effort of making any forceps self retaining since the time of the Bronze Age When Heister a German surgeon published his book in 1719 the illustrations showed the original catch invented about 550 B C and also two artery forceps of contemporary usage

We are less surprised to read of Celsus (Aulus Cornelius 53 B C – A D 7) description of a flap operation when we recall that it is almost certain that he was acquainted with the ligature as a means of checking hæmorrhage Celsus recommends a flap should be dissected up and the bone divided at a higher level In his description of the amputation of a gangrenous limb he writes It must be divided with the saw close up to the sound flesh The end of the bone is next to be smoothed where the saw has left any asperity Surgeons of his time were obviously in too great a hurry to complete the operation to think of flaps

The decline in surgical technique that followed the collapse of the Roman Empire is illustrated by the following summary of the crude methods of amputation that were current up to the sixteenth century

Cut through if you will all the parts at the same level with a red hot knife like Fabricius Hildanus by a single blow with chisel and mallet like Scultetus by a crushing guillotine like Purmanus or like Botal, by two butchers chopping knives set in heavy blocks of wood one fixed the other falling in a groove Then try to check the bleeding by tying a pig s bladder over the face of the stump like Hans von Gersdorff by tying it up in the inside of a hen newly killed or by plunging it at once into boiling pitch *

Hans von Gersdorff who was a German army surgeon and an experienced operator flourished about 1500 In 1517 he wrote a book on military surgery in which he describes how after an amputation he applied a bandage without sutures and checked hæmorrhage by a caustic plaster His saw had a removable blade fixed by a screw and hooks at each end of the frame to enable it to be hung on a wall or on the pole of a tent

The wounded soldier or victim of an operation who had hæmorrhage which could not be stopped by pressure of the hands or sponges had his bleeding stopped by two standard remedies— red hot cauteries (black heat only should be used—Bryant) or boiling oil Scultetus in his book shows a picture of an amputation of the hand at the wrist performed with a very broad osteotome which went through the wrist in one blow This was a merciful proceeding in its way and, curiously enough, the picture shows a bandage round the wrist which makes one feel that even at that time (1595–1645) the elements of a tourniquet were in existence But the unpleasant part about the picture is the bowl of boiling oil and the array of cauteries

Things had remained like this throughout the middle ages until the advent of Ambroise Paré the Father of French Surgery (1510–90) He was no ordinary surgeon Despised by some of his colleagues because he knew no Latin he had a weakness for puppy dogs fat as a wound dressing He became an army surgeon in 1536 and was successively surgeon

* Joseph Bell. A Manual of the Operations of Surgery " (1866)

to Henri II François II Charles IX and Henri III of France He was a Protestant and so well beloved that Charles IX hid him in his room during the frightful massacre of his co religionists in Paris on the Feast of St Bartholomew This gentle surgeon who took for his motto Je le pansay Dieu le guarit (I dressed him God healed him) re-introduced the ligature for tying off arteries about 1552 Paré also invented artery forceps similar to the pliers used by carpenters to-day but these had a strong spring between the handles to assist in keeping them closed while he was tying off the bleeding vessels

The evolution of the basic design of artery forceps lingered at this point for very good reasons The instrument maker had not made his contribution to the tools of surgery The surgeons were working with tools of a very simple and elementary design and for about two and a half centuries there was no progress in the design of instruments As an example in Heister s book A General System of Surgery (1743) which has thirty-eight copper plates of instruments there is not shown one pair of self holding forceps or forceps with a rack or a catch spring in the whole collection

An instrument in common use later as a substitute for the artery forceps was the tenaculum designed by Sir Charles Bell (1807) This was an improvement on the already existing sharp hook A blood vessel could be picked up with the point of this instrument and then tied off This had preceded Assalini s forceps and in 1847 Robert Liston introduced the double tenaculum-dissecting type of artery forceps with a spring catch while in 1855 Wakley son of the founder of the *Lancet* improved Liston s forceps by designing the fenestrated jaw over which it was easier for the loop of the ligature to slide Forty five years later Arbuthnot Lane of Guy s Hospital London who had been using Wakley s forceps as tissue forceps had the Wakley end put on to the Spencer Wells type of shanks and these became the celebrated Lane s tissue forceps

With the universal régime of asepsis to-day the use of artery forceps for torsion only has ceased The ligature to-day is not provocative of sepsis and torsion is a method only carried out on small vessels by an ordinary artery forceps

The Tourniquet. The first tourniquet known was the Garotte invented in 1674 by Morel who used it during the siege of Besançon The tourniquet was introduced into England by James Young of Plymouth in 1678

The first generally accepted tourniquet was Esmarch s bandage This bandage is made of a superior type of indiarubber and acts not only as a tourniquet but also as a means of producing a bloodless field for certain operations on the limbs

This technique was detailed in Volkmann s *Sammlung Klinischer Vorträge* No 58 The result of the bandage application was described in Esmarch s own words —

> We now remove the elastic bandage and the oil silk, and you will notice that both legs below the tourniquet present the appearance of the limbs of a corpse the pallor of the same forming a remarkable contrast to the rosy hue of the skin above. You will also notice that we will operate exactly as though on a cadaver After the operation the rubber cord is slowly removed and the circulation restored and those arteries which have previously remained unnoticed tied

The inventor Friedrich von Esmarch (1823–1908) was a pupil of Stromeyer and von Langenbeck and a pioneer of surgery in Germany He did much to improve the status of military surgery He introduced his rubber bandage in 1873

In 1901 Lynn Thomas introduced a tourniquet forceps evolved from Doyen s broad

ligament forceps in order to control the femoral vessels in high amputations of the thigh and for interscapulo thoracic amputation. The forceps has two blades the one probe pointed and the other flat and serrated Each is about 12 in from handle to point

FIG 3 "Shews the manner in which the Patient Surgeon and Affiftants are to be placed for amputating the Hand or Arm. A denotes the Patient B the Surgeon amputating with the Saw; C the Affiftant extending the Hand; D another Affiftant holding the Arm; E the Affiftant who holds the Patient's Body and takes care of the Tourniquet; F denotes the Difh or Veffel placed underneath, to receive the blood."

(*Heister A General System of Surgery* 1743.

and the flat blade in some models is terminated by a flat ring for more efficient compression

The method of application is well described by Lynn Thomas in his article "Emergency Amputations in Military Surgery" (*British Medical Journal* 1916 2 482) —

> Many of those who have seen the forceps tourniquet in use have adopted it. Binnie, Jacobson Kocher Charles Mayo and Tuffier have all spoken with enthusiasm of its usefulness A stab puncture of the skin is made at a point suitably placed in relation to the vessels to be controlled and through it the probe-pointed blade is driven forcibly behind the large blood vessels (femoral artery and vein). When the forceps is closed the other blade firmly grasps the skin, and, owing to its roughened edge and the expanded ring end does not slip. The time occupied in applying the forceps is not more than a second

To-day improved methods of anæsthesia and resuscitation have made the speed

factor of less importance in such procedures The main vessels are dissected out and ligated before continuing the operation

Anæsthetics An important reason for the slow progress in operative technique in amputations was the background of pain against which the surgeon operated Celsus wrote the following description of the character of a surgeon That he should have an intrepid mind void of all tenderness and pity and entirely deaf to the shrieks and outcries of the suffering patient

The Talmud tells us that anæsthetics both local and general were employed in major-operations A drug or potion was used to induce sleep lessen pain and allow increased leisure in operating A similar drug was also given to capital criminals before their execution in order to benumb their senses and to spare them any physical pain

The use of the word anæsthetic was suggested by Oliver Wendell Holmes in 1846 when he was professor of anatomy at Harvard University He was a friend of William Thomas Green Morton who was responsible for the use of ether anæsthetics for a publicly conducted operation, in the same year In 1844 Horace Wells another American had used nitrous oxide Sir James Young Simpson of Edinburgh University first used ether and then introduced chloroform which he considered to be much safer for use in midwifery

It is only within the last twenty years however that the art of keeping a patient lightly anæsthetized and producing muscular relaxation and analgesia has been fully developed This method has given surgeons the opportunity to improve technique to operate confidently and with modern methods of sterilization to expect success and complete recovery

FIG 4 A woodcut showing an amputation below the knee—1731 No anæsthetic.
Garengeot Traité des opérations de chirurgie 2nd ed., 1731

The Ancient Period In the Old Testament the only surgical operations mentioned are circumcision and castration the latter being prohibited (*Deuteronomy* ch 25 and *Leviticus* ch 22) The ancient surgeon realized that he had a duty to repair broken arms and legs by setting fractures and binding them together and that when conservative measures failed amputation had to be performed

With advancement in knowledge removal of an extremity because of disease deformity or injury slowly became an established scientific procedure Wars have been with us since the earliest historical times. With wars came battle casualties many of them requiring amputation and the military surgeon of those days became essentially a

bone surgeon. The criterion for amputation was founded upon the Hippocratic precepts

When gangrene supervenes in a fracture the soft parts separate quickly as for the bones they become detached at the limit of their exposure but much more slowly It is necessary to remove whatever dies first below the lesion from the healthy parts avoiding pain as far as possible for the patients die from fat embolism Thus the ancients performed amputations to remove useless members to reduce invalidism and to save life

During the Talmud period (*circa* A.D 200–500) surgery attained a high degree of development The knowledge and practice of this skilled craft was quite advanced among the authors of the Talmud many physicians among them devoting themselves exclusively to it Many minor as well as major operations were performed. In addition to the treatment of dislocation of various joints or fractures by means of splints trephining venesection, and the application of orthopædic appliances mention is made of major amputations in cases of leprosy and other dangerous infections

During the Middle Ages the loss of arms and legs was very great This was due in part to the devastating effects of leprosy and ergotism

With the introduction of cannon-shot (first used in the battle of Crécy in 1346) and half pound gun-shot (used at Perugia in 1364) the resulting wounds proved so mutilating that amputation became necessary

In more modern times with the use of instruments the tourniquet ligatures and later of anæsthetics and asepsis surgeons had time to look about for improvements during an operation and particularly to try to get a good covering to the bone so that the stump might heal more rapidly and bear pressure better Great improvements were made and any history of such improvements would need to trace two great parallel lines —(1) the cutting of the soft parts by the circular method and (2) the flap operation

The old method the true circular as it might be called in which the limb was cut through in one sweep all tissues being divided at the same level has been attributed to Celsus and has now only a limited field of application. This however was later improved upon —

(*a*) *By Cheselden and Petit who invented the double circular incision* in which first the skin and fat were cut and retracted and then the muscle and bone divided as high as exposed.

(*b*) By Louis who improved this by making the first incision to include the muscles also The bone alone was divided at a higher level.

(*c*) By Mynors of Birmingham who dissected the skin back like the sleeve of a coat to gain more covering

(*d*) Then by Alanson who first cut through the skin and fat allowing them to retract and then exposed the bone still further up by cutting the muscles obliquely so as to leave the cut end of the bone in the apex of a conical cavity

(*e*) By the simpler triple incision of Benjamin Bell of Edinburgh (1788) which achieves the same result He also taught that the skin and fat should first be incised and retracted then the muscles and lastly the bone divided.

(*f*) A slight improvement on (*e*) was made by Hey of Leeds who recommended that the posterior muscles of the limb should be divided at a lower level than the anterior to compensate for their greater range of contraction

In the development of the flap operation fewer stages can be observed Progress however has been made by cutting from within outwards In shape size position and

number the flaps vary from the single posterior one of Verduin of Amsterdam to the two equal lateral ones of Vermale and lastly, the equal anterior and posterior ones of the Edinburgh School

Then came the rivalry of the schools Flap or Circular

Flap Robert Liston (1837) advocated the flap method He used digital pressure instead of a tourniquet and dissecting by transfixion This was speedy, easy and less painful but the skin was apt to retract unequally

Circular This left a smaller wound but operating time was longer and it was apt to leave a central adherent cicatrix

The present stage in amputation began after the introduction of anesthetics Then speed became a secondary consideration and was necessary only in special cases The surgeon had ample time to model his flaps into the curves most suited for accurate apposition and suitable relation of the cicatrix to the bone It had also been established that different methods of operating were suitable for different situations and even in the same operation it was possible to combine the advantages of both the flap and the circular methods

A modified circular incision, which is best suited for amputation below the knee was then adopted In the long anterior flaps of Teale Spence and Carden, we have illustrations of the manner in which the advantages of both flap and circular methods have been secured without the disadvantages of either

The long anterior flap (unlike Teale s which folds upon itself but like Spence s and Carden s) hangs over and shields the end of the bones and is now the typical method for successful amputations

Fig 5 A sixteenth century amputation A wood cut from a book on surgery published in 1517 and said to be the earliest pictorial representation of this operation Amputations were frequent then and continued so until Lister introduced the antiseptic principle late in the nineteenth century After that time many of the infected wounds which formerly led to amputation could be controlled by antiseptics and amputation thus avoided The patient shown in the woodcut is enduring the pain of his operation without anesthesia, and so did all patients until the middle of the nineteenth century

[Gersdorff Feldtbuch der Wundartzney 1517

Antisepsis In the *Lancet* in 1867 Joseph Lister published his observations on antisepsis and so profoundly altered surgery and amputations Prior to the Listerian period hospitals were houses of death but with the adoption of his principles by the world there began the age of scientific surgery and the patients who needed amputations were the first to benefit

Artificial Legs. *Prosthesis* is a Greek word meaning addition (*pros* to *thesis*

a placing) In surgery prosthesis means the making of artificial parts and fitting them to the body As long as amputations have been practised surgeons have tried to replace the lost limb

Stumps were first bound up in long splints and crutches and wooden pegs were used for supports It is however extremely difficult to establish the exact date when prostheses were first employed. The Greek historian Herodotus (b 484 B C) mentions a picture from Italy showing an appliance which consisted of a simple wooden capsule This same type of prosthesis is depicted on an old Perugian vessel. I have been able to establish an early authentic reference in which from a discussion between Rabbis Meir and Jose (about A.D 140–165) it can be ascertained that the sufferers were supplied with artificial limbs Mention is made in the Talmud of a wooden stump given to a cripple of the padding put into the concave top of the wooden leg to protect the end of

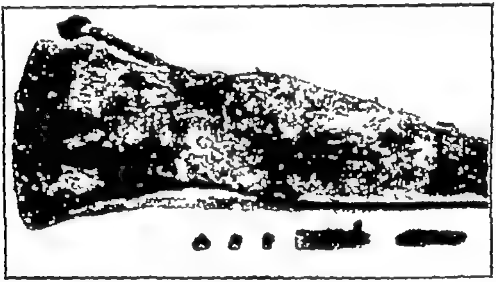

FIG 6. Roman artificial leg of bronze found in an undisturbed tomb at Capua with some vases which, from their style date from about 300 B C.

[*From Thompson, The History and Evolution of Surgical Instruments. Henry Schuman, 1942. Reproduced from the Museum of Royal College of Surgeons of England.*

the limb of a man whose leg had been amputated, and of the leather knee pads that protected his extremities while shuffling on the ground

An artificial leg of remarkable workmanship was found in a grave dating back to 300 B C This prosthesis had metallic side bars made of thin bronze which were fixed by bronze nails to a wooden base This was the oldest known artificial limb in existence and was in the Museum of the *Royal College of Surgeons of England.* It was unearthed at Capua in Southern Italy and it is said to date back to the Samnite wars about 300 B C at the time of the Roman Republic Unfortunately this priceless specimen was destroyed in the disastrous fire at the Royal College during an air raid in May 1941

Herodotus tells of a seer Hegesistratus who when he was imprisoned by the Spartans and condemned to die effected his release by cutting off the foot by which he had been chained in his cell He fled to the city of Tegea which was thirty miles away and there after the wound had healed he was able to provide himself with a wooden leg *Most of these prostheses although comparatively crude illustrate the* endeavours of man to overcome the handicap of an amputation of a limb

Artificial Arms. Pliny makes mention of Marcus Sergius who lost his right hand

during the second Punic War (218–202 B C) He was fitted with an iron hand, which he used with great effect

An artificial hand dated about A D 1400 and made of iron is described in Acta Sanctorum and other mediaeval chronicles, which also discuss wooden legs and artificial appliances for amputations The hand with fragments of armour was reclaimed from the Rhine mud Gurlt published several drawings of this apparatus which was placed in this particular period because an analogy exists between this iron forearm and apparatus worn by a German knight Goetz von Berlichingen who achieved fame as the champion of the peasants against the nobles This knight lost his hand in 1509 during the siege of Landshut in Bavaria His exploits were the subject of one of Goethe s dramas In this we read that when the monk Martin asked his name the warrior offered the monk his left hand Martin was offended Why do you offer me the left hand am I not worthy of knightly courtesy ? To this Goetz replied Were you the Emperor himself you must be content with this My right though not useless in war is insensible to the pressure of love It is part of my glove you see it is made of iron Martin bowed and kissed the iron hand which revealed to him the name and heroism of the altruistic captain

Later in this work Goetz speaks thus of his iron hand It has rendered more service in the fight than ever did the original flesh This warrior had several hands made which were movable in the joints and had flexible fingers capable of closure

Several copies of his hand were made There was one in the Museum in Vienna reported to have been constructed for the Emperor Joseph II Another existed in the armoury of Bredow of Wagnitz (Mannheim) A third hand is in the famous Meyrick collection in Wales

Guido Guidi, a Florentine surgeon who practised at the Court of Francis I of France and died in 1569 wrote of a patient whose forearm had been amputated and replaced by a metal one This new forearm not only served as an ornament but was quite useful

A more descriptive account was given about 1590 by John Minadoi, a physician to William Gonzaga Duke of Mantua and a professor in the University of Padua who travelled widely in the Orient He stated that he met a man who had lost both hands Fitted with an iron apparatus he could remove his hat open and shut his purse and sign his name Another man had lost his right hand and could still accomplish many acts with his improvised hand

There are more scattered references to be found relating to the sixteenth and seventeenth centuries Mention is made of an artificial hand that was used by a Huguenot general in the French wars, after he had lost his hand in the battle of Fontenoy This lost hand was replaced by a metal one which he used dexterously and he came to be known as The Iron Hand

Ambroise Paré (1510–90) No description of limb making or surgery of this period would be complete without mentioning this great pioneer Not only did he contribute as we have seen to the surgery of his time but he provided his patients like a true surgeon, with as useful a substitute as he was able to procure An artificial hand which was depicted and described by Paré in his book on surgery was constructed in Paris in 1550 It was called le petit Lorrain The dorsum of the hand had the form of a steel gauntlet the thumb was rigid and the fingers were kept extended by four springs which were fixed to the palm Paré also portrays another upper limb in which the mechanism

controlling flexion and extension of the elbow is clearly shown and easy to understand An artificial leg illustrated in the same volume on surgery was made of sheet metal plate This resembled a piece of armour which covered a peg leg for a thigh amputation It had a joint at the knee so that the wearer could flex his knee whilst sitting For the first time in the history of amputation a sympathetic approach is noted

An engineer in Boulogne who inherited a family legacy found among his bequests an artificial lower limb which had been constructed about 1616 It had been made for the Marquis Francis Riarrio (1615–74) and has been called the Zucchini limb after the name of its originator Putti who examined the limb was doubtful as to the exact type of amputation it was intended to replace or the type of deformity for which it had been designed He opened the tomb of the Marquis but found nothing He drew conclusions from an examination of the artificial limb itself which he believed was for a right leg and had been made for a deformity It compensated for a short and deformed leg and foot

These relics are historically interesting indicating landmarks in surgical history Although many of the appliances were never used they show that the craftsmen who constructed them had a definite object either functional or æsthetic or both Some of the hands described may be well termed working appliances not unlike those we use to-day which enabled the wearer to accomplish some definite action either by pressure or grasp

The soldier knights of past ages desired to conceal some of their mutilations They considered that the scars of battle were not marks of courage but rather an indication of inferiority For this reason the designer of armour would conceal the soldier s loss by making the armour a copy of a complete body

The limb manufacturers of the fifteenth and sixteenth centuries were also makers of armour and weapons and their work therefore reflects the influence of an art of the period which had reached great perfection both in Italy and in Germany

From the fifteenth to the seventeenth century the purpose of the limb-maker was to restore function to casualties of war—limbs lost in battle The wearer desired primarily a workable hand for holding his lance or sword If this was not possible his only object was to hide his deformity

Appliances to disguise deformities of the leg were also constructed especially in the case of a knight so that he could mount a horse Rarely were prostheses constructed in an effort to help the manual labourer or to improve the appearance of the artisan who had lost a limb But in many of the crude appliances which were made there can already be seen the architectural principles upon which the modern prosthetic art is founded

Because of perpetual warfare amputations were undertaken on a great scale amputations being easier than excisions The German army surgeon Bilguer pleaded for a more conservative attitude towards gunshot wounds instead of amputations. In those pre-anæsthetic days the speed and ease of amputations were a temptation to prefer them to the more difficult excision of joints

The Nineteenth Century This century produced many advances in prosthetic development due primarily to the great advances in amputation surgery

In 1818 Peter Ballif a Berlin dentist made a notable contribution To him must be given the credit for first introducing the use of the trunk and shoulder girdle muscles as a source of power to flex or extend the fingers This method has since been generally adopted in the manufacture of arms and hands

Ballif's arm was designed for a forearm amputation for which no elbow flexing mechanism was needed

The first arm for the above-elbow amputation in which Ballif's principle was applied to flexion of the elbow was that invented by a Dutch sculptor Van Peeterssen and submitted to the Academy of Sciences in Paris in 1844 This prosthesis was reported upon favourably by Magendie A catgut cord attached at its upper end to a special corset behind the sound shoulder was passed into the back of the upper arm segment of the prosthesis over the front of a ball at the elbow to be inserted into the back of the artificial forearm Flexion or abduction of the stump and socket by separating the points of attachments of the cord tightened it and pulled up the forearm into a flexed position Other cords extended the spring closed fingers on extension of the elbow and abduction of the arm

Karoline Eichler a Berlin instrument maker developed Ballif's principle in the construction of a new hand In this case the normal position of extension was maintained by spiral springs while flexion was effected by means of catgut cords which were controlled by the opposite shoulder This arrangement is the converse of Ballif's principle Flexion of the artificial elbow joint also bent the fingers In Eichler's hand all the fingers were locked The obvious criticism of this hand from the point of view of manufacture is that catgut cords cannot be very durable

A simple and crude hand by Clasen which was produced in 1886 embodies the principle of the worm-gear which is successfully used in Carnes arm This gear is meant to be worked by friction of a milled wheel which projects from the back of the hand against any flat surface It may obviously be worked also by the sound hand This is the first occasion in which an attempt is made by an artificial hand to grasp a heavy object firmly The fingers in this hand are not jointed except at the metacarpo phalangeal joints.

The Carnes' Hand In 1904 Carnes an American invented an ingenious hand In many respects this is one of the greatest inventions of its kind that has been made It has the disadvantage of being made of steel and is therefore heavy weighing 16 to 24 oz but it has the great advantage of adaptability and supination and pronation in various positions of flexion are possible making it easy to use and thus increasing its value

In Carnes hand flexion of the elbow is accompanied by supination of the forearm at the wrist joint so that the hand can be brought automatically to the mouth This important function enables the palm to be brought to the mouth or face instead of the radial border of the hand This unique action of an artificial hand adds to the natural ease of movement and enables the wearer to convey food and drink to his mouth Action such as this is of value in a single amputation but its value in a double arm amputation cannot be over-estimated It is not however, always desirable that elbow flexion should be accompanied by hand supination and provision is made in the Carnes hand to deflect the latter motion by a simple device

The action of the fingers and thumb is one of simple flexion and extension The fingers when they are closed become locked so that they are much more resistant than those hands which depend upon springs for resistance to extension This is effected by a mechanism contained in the hand one for the above-elbow and one for below-elbow arms In the above-elbow arm there is only one source of power available for the fingers

The mechanism is so constructed that one pull opens the fingers and if this pull is repeated the same thong closes the fingers. In the below-elbow arm there are two sources of power available as the one source is not now required to flex the elbow. When pulled upon, one thong opens and the other closes the fingers.

As will be seen in a later chapter dealing with kineplastic surgery this method is further employed by tunnelling these muscles as introduced by Vanghetti (1906) in his cinematization. The method of using the power of these muscles as described by Ballif is the extrinsic control, and it can be contrasted with that which was described by Vanghetti as the intrinsic muscular control.

The Present Era. Our modern way of living our desire for speed, and our increased facilities for travel are responsible for more amputations in peace than in war. It is producing a problem which requires serious consideration on the part of the limb-fitting service. The amputee of to-day cannot and should not be allowed to resign himself to a life of disability.

Formerly the provision of a prosthesis was concerned chiefly with concealing the loss of a limb. To-day it implies and demands that a patient should have a useful replacement of his natural limb. The surgeon, by the correct application of his skill and scientific knowledge and by his attitude to the amputee is responsible for the future happiness and usefulness of his patient determining whether he will be able to take his place in the pattern of society or come instead to regard himself as a hopeless cripple.

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CHAPTER II

GENERAL PRINCIPLES OF AMPUTATION

Study principles rather than methods A mind that grasps principles will devise its own methods.

A. Bruce Gill.

While amputations should be elementary in principle the fact is often overlooked in practice that every amputation should be planned as a geometrical mechanical and anatomical problem

The principles which guide us in carrying out an amputation vary according to whether the section is to be an urgent amputation or can be a delayed planned procedure through healthy tissue (*definitive amputation*)

When dealing with a definitive amputation the result anticipated is healing by first intention with a final and permanent stump as the aim *Great care is necessary to* ensure that the stump will be painless and durable and therefore suitable for limb-wearing

Indications

The operation may be advised as a life-saving measure when the patient s general condition is deteriorating owing to the diseased condition of the limb

A grave septicæmia may arise from an infection in a limb which cannot be controlled by conservative surgery and chemotherapy and thus the limb threatens life Amputation is frequently required owing to a local condition rendering the limb useless as in crushing accidents where the limb has been irreparably damaged An urgent amputation may be necessary to prevent the local or general spread of infection in cases of gas gangrene of a whole segment of the limb

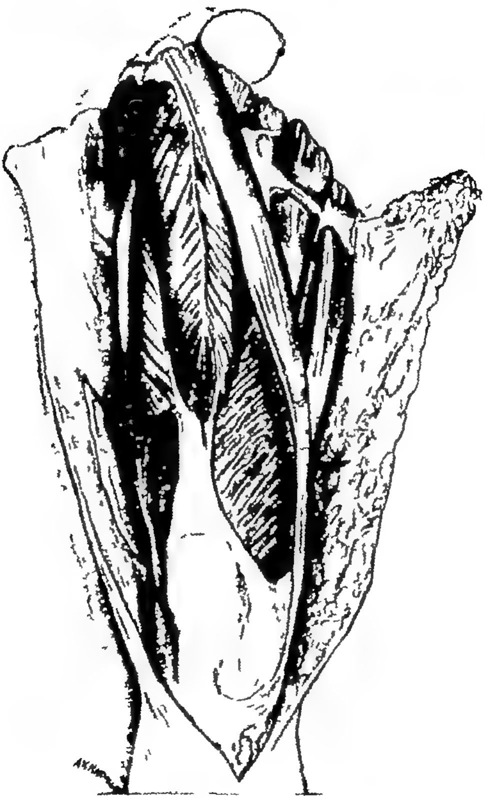
Excluding the well-defined and absolute indications for an amputation such as proven malignancy the decision as to whether or not a limb should be amputated, can be very difficult It is unwise to give exact directives as the surgeon should use his clinical experience with due appreciation of the relative importance of all circumstances

The choice between the best artificial limb and the imperfect natural limb can be made only on a broad pattern of experience This involves a knowledge of what a patient supplied with an artificial limb can accomplish In assessing an injury or a disease for amputation, the presence or absence of sensation should be given high priority value even before muscular power because this quality still evades imitation.

The ultimate decision as to whether or not an artificial limb is going to benefit the patient will depend on the physical powers and the mental make up of the individual A good artificial limb will not succeed even in the presence of good physique if the patient s psychological make up sets up some latent aggravating focus as a barrier

A healthy central nervous system and a cardiovascular system which if not healthy should be well compensated will enable the patient to wear an artificial limb Diseases, like tabes dorsalis and syringomyelia require amputation purely on medical grounds.

PLATE I



Advanced gas gangrene of thigh affecting the vastus externus and the rectus femoris.
("Surgery of Modern Warfare," Hamilton Bailey, Part II 3rd Edn. E. and S. Livingstone

[To face p. 18.

A double above knee amputation requires physical powers mental equilibrium and will power of a high order Unless *surgical indications are overwhelming* operation should be deferred A practical analysis should be made of the whole make up of the patient including his social and economic conditions

Having regard to the above statements the following groups of conditions indicate when an amputation may be required

Indications for Operation

✓

1 Trauma
2 Gangrene (*a*) spreading (moist)
(*b*) painful (dry)
(*c*) gas
(*d*) sepsis
3 Some cases of chronic infection e g pyogenic and tuberculous infection of bones and joints
4 Some cases of ulcers or contractures of soft tissues
5 Tumours
6 Some cases of deformity or extensive paralysis
7 Aesthetic considerations (Chapter VIII)
8 Re-amputation for complication of primary amputation (Chapter IX)

Immediate Indications

1 **Trauma.** During the Second World War the Medical Directorate sent out instructions emphasizing the need for immobilization resuscitation and conservation of all tissue when dealing with severe casualties in the front line and at casualty stations Definitive surgery was discouraged before the patient reached advance base hospitals except for the very few cases dealt with by field surgical units

In such cases the surgical and prosthetic principles might be overlooked because of the urgency of the condition but the aim should be to conserve every possible inch of sound limb In below knee cases a rapid disarticulation at the knee would suggest itself if there is gross damage to the leg but again every effort should be made to preserve as much tissue as possible

In amputation on the battle field we are justified in sacrificing only that amount of limb necessary to save life and to combat infection Surgeons in the field should not concern themselves too much as to whether to amputate at the optimum site they should be content to amputate at the lowest possible site They should keep in mind only the saving of life and limb

I am of the opinion that skin flaps should always be cut The flaps should be lightly sutured With the increased use of antibiotics and sulphonamides the necessity for a guillotine amputation is lessened and it will probably never be required again

The following principles require emphasis —

(1) Emergency operations should be performed through or immediately above the level of the trauma without regard for the ultimate prosthesis The site should depend on the level of bone injury rather than on the highest level of the soft tissue loss
(2) Viable skin should never be sacrificed unnecessarily Flaps should be cut but

not too oblong · The preservation of skin beyond the level of amputation permits of early healing combats infection rather than encourages it and improves the definitive surgery if necessary. During the last war we did not always find it necessary to perform re amputations, and some of the cases are wearing comfortable artificial limbs to date

(3) The amputation should be as simple as possible, with no attempt at resection of periosteum or the injection of nerve trunks.

There are several conditions in which this radical procedure must be immediately

Fig Severe bilateral burns of both feet and charring of bones. Below knee amputation (E O S. Kerlin

considered and others in which the necessity for it arises out of the original trauma but at a later date

(*a*) An Incarcerated Limb In mining casualties or in an air raid, a leg may be fixed by an immovable object ; Amputation on the spot is indicated just as amputations in the battle-field may sometimes be indicated

(*b*) Crush Injuries

(1) The limb may be practically severed by an accident or mangled with extensive comminuted fractures and lacerations and its removal is necessary

(2) There may be extensive injury to blood vessels associated with an open wound involving a joint or severe fracture and a primary amputation may be indicated

(3) If the leg is cold and pallid with solid œdema the toxic effects of damaged tissue products will almost certainly produce renal failure in three days or less and primary amputation as a life saving operation becomes necessary

(4) If the crush syndrome develops in a doubtful case and the renal excretion falls off while azotæmic findings confirm the diagnosis amputation is still advisable though medical measures are also required

(c) BURNS OF THE LEG destroying the whole skin of the limb may be an indication for amputation Primary amputation by as conservative a method as possible is advised, and slightly burned skin may be retained in the stump

No burn injury is considered hopeless unless the main vascular supply to the lower

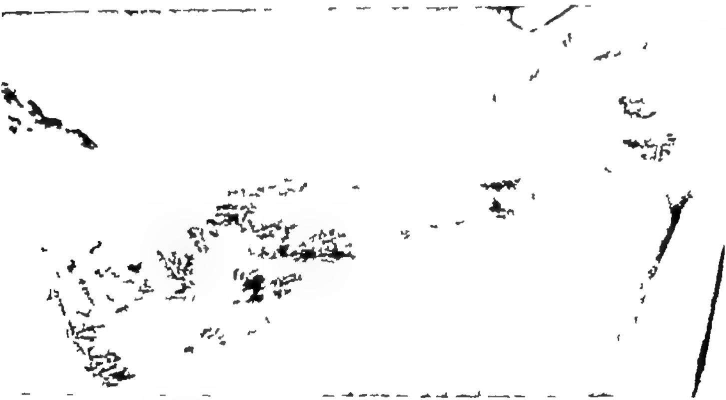


FIG 8. Dry gangrene Thrombosis of the femoral artery Above-knee amputation.

fragment is completely destroyed If this is so amputation is necessary A wound with a fracture and peripheral nerve lesion does not necessarily demand immediate amputation The presence of lacerated fascia and muscle foreign bodies and dirt in an open wound are not absolute indications for immediate amputation If operative treatment has not been possible and evident infection has gained a foothold and is progressing rapidly the necessity for removal of the limb may increase hourly

(d) DEGLOVING where the whole skin is torn off as in road accidents Even Reverdin grafting of the deep tissues is excluded by the vast amount of graft necessary

2 **Gangrene** Some form of amputation is usually required for gangrene but this does not mean that the necessity for amputation arises as soon as gangrene is diagnosed General treatment including rest in bed is advised for conditions such as all forms of vascular disease with or without diabetes mellitus while intra arterial injections

sympathectomy or arterial grafts may prove helpful before consideration is given to amputation There may be extensive infection when the condition is first diagnosed, but the patient may be responding to treatment of such modern therapeutic agents as for example, penicillin streptomycin the sulphonamides or insulin. Amputation can then

FIG 9 Extensive bone infection of lower end of femoral shaft with septic arthritis. This was not arrested by any form of treatment and finally a high above-knee amputation was found necessary

be undertaken at a more favourable level and when the condition of the patient has improved.

3 **Infection of Bones and Joints** There is no doubt that in the last war lives were lost because surgeons often tried to save limbs when the patients were rapidly losing ground owing to toxæmia, in spite of modern therapeutic agents. When in any joint the suppurative processes continue to extend in spite of adequate drainage blood transfusions and the most modern chemotherapy and the deterioration in the general condition is shown by fever loss of appetite wasting sleeplessness and general appearance it becomes obvious that the infection is undermining the patient's strength and amputa

FIG 10 Shotgun injury of right forearm and hand with infected compound fracture Sinuses and useless remaining digits.

FIG 11 Old compound fractures of shaft and lower end of ulna. Damage to carpus. Multiple metallic foreign bodies widely scattered over forearm.

tion is required I can recall regretfully one or more occasions when I delayed too long before performing amputation. Amputation may be advisable in chronic cases such as when amyloid disease is threatened or when multiple sinuses and deformity exist in a limb The patient will enjoy better health and will have improved limb function after the operation

In children amputation may very occasionally be performed as a life-saving procedure but with efficient conservative and antibiotic treatment it is only rarely necessary and then only when tuberculous disease in bone is accompanied by extensive tuberculous infection of the lungs or kidneys. In elderly patients however when the disease is progressing in spite of conservative treatment amputation is the only alternative and should be undertaken as soon as possible It may be that streptomycin therapy will in future improve the prognosis in these cases Case Report—

D M Aged 21 Sustained a shot-gun wound of the right hand and forearm on 24.8 42.

X ray showed compound fracture of the radius and ulna. These failed to produce bony union Slow healing continued with immobilization in plaster until the end of October and from then until December 16th he was in a Bunyan bag

At operation on December 16th the middle finger which was now the most medial finger since the ring and little fingers had been lost at the time of the accident, was gangrenous and was therefore removed and with it a sequestrum from the ulna.

After this second operation the arm healed much more rapidly with the aid of antibiotics in the form of procaine penicillin, 500 000 units, and streptomycin, ½ gm b d

On three occasions since the end of February 1950 every time the chemotherapy had been stopped the patient developed cellulitis just below the elbow and marked lymphangitis and axillary adenitis. The cellulitis subsided and a discharging sinus appeared at the top of the scar tissue The sinus was explored and no sequestrum or pellet was found to account for the infection. The patient continued to have flare ups.

Examination on 31 3 50 the index finger is flexed at both interphalangeal joints, is stiff and immobile but with no feeling The thumb is present and he has a little movement for opposition to his index finger

The forearm shows a large scar on the ulnar border with two discharging sinuses, one in the neighbourhood of the wrist and the other in the neighbourhood of the hand.

He has full elbow movement and is a naturally left handed man.

As a tractor driver the remaining fingers were useless apart from the fact that he was having pain and flare ups.

8 6 50 a below-elbow amputation was performed using a long flap of good skin to cover the 5-in. stump. Many lead bullets were removed together with a sequestrum from the ulna. The wound healed well after some local inflammation

He was measured for a prosthesis on 25 8.50 which was supplied in ten weeks and he has returned to his former employment

4 **Ulcers, Infections or Contractures of Soft Tissues.** If a patient has suffered from such lesions for many years there may be so much limitation of function that his economic condition is affected In many cases amputation will enable the patient to return to his work and enjoy good health

5 **Some General Considerations in Amputations for Neoplasms** The diagnosis of course should be established beyond all reasonable doubt There should be clinical radiographical and histological data where possible There should always be an X ray of the chest and any other likely site for metastasis having regard to the nature of the growth and its known pathological tendencies In most respects an amputation for a tumour is the same as an amputation elsewhere Hæmorrhage should always be borne

FIG 12. Long-standing (thirty five years) ulceration with elephantiasis and epithelioma. Below knee amputation

in mind and suitable precautions taken A blood transfusion should be prepared and as in all blood transfusions cross matching performed and the Rh factor ascertained.

In the radical surgical procedures which are mentioned in addition to blood transfusion the large vessels should always be ligatured as a first step in the operation Where possible conventional flaps should be used but the location of the tumour may necessitate using atypical ones

Primary wound healing is the aim and tension should always be avoided It is better to modify long flaps than to have to shorten the bone to accommodate the stump within the flaps

If the regional lymph nodes are suspected they should be excised at the same

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best way out This is exceptional and in the upper extremity especially, should be resorted to only when no alternative exists

(c) Squamous Epithelioma A primary squamous epithelioma is not an indication for amputation it is usually treated by local excisions or radiotherapy A series of cases have been reported in the literature (Gillis L, and Lee S, *Journal of Bone and Surgery* 1951) in which carcinoma occurred as a sequel to discharging sinuses resulting from gunshot wounds In all those there was chronic osteomyelitis with a discharging sinus which had persisted for twenty or thirty years

In these cases where conservative measures had failed it was of importance to perform early amputation because contrary to what had hitherto been believed, these

Fig 14 Carcinoma at the site of a deep ulcer crater of the foot in relation to the calcaneum. Skeletal traction by calcaneal pin twenty-one years previously led to infection and chronic sinus.

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tumours invaded widely and metastasized If metastases did not occur and the cancer was not eradicated amyloid disease became a complication There can be no doubt that some of these lives could have been saved if early amputation had been performed

(d) Neurofibromatosis and extensive congenital pigmented moles of the lower extremity which are occasionally seen in children do not yield to conservative measures and the possibility of malignant change must be borne in mind It is frequently a method of choice to save the child many long and futile surgical operations by amputating the limb at the site of election

(e) Malignant Tumours in Bone

(1) *Endothelioma of Bone* (*Ewing's Sarcoma*) This lesion becomes generalized so soon that amputation seldom serves any useful purpose It is however very

operation In the groin or axilla, these nodes can be dissected out through the same incision if the operation decided on happens to be high up towards the trunk. In the case of glands in the axilla or groin, where the amputation is distal, the amputation should be a primary step in the operation and then the regional glands should be removed

(a) BENIGN TUMOURS The presence of these seldom necessitates amputation An osteoma of bone can be chiselled off without fear of recurrence, while chondromas can be

FIG. 13. Chronic discharging sinuses (thirty years) with elephantiasis of forearm. Biopsy epithelioma. Deep X ray therapy

removed by local excision, except in the case of a painful useless finger the site of a chondroma when amputation often becomes necessary If this tumour recurs after excision the probability of malignant change should be borne in mind This can be seen in the case reported below and the X rays shown After two attempts at local removal the chondroma assumed malignant characteristics.

(b) OSTEOCLASTOMA (GIANT-CELLED TUMOUR) Amputation is indicated only if there is such gross destruction that arrest of the tumour will not give a useful limb Arrest can almost be guaranteed by deep X ray therapy in a dosage of 2 000 roentgens. Occasionally it is obvious from the radiogram that the removal of the tumour will involve the joint and so greatly disorganize and weaken the limb that an amputation is the

FIG 16. Sarcoma upper end of tibia. Later treated by above-knee amputation.

his end. If amputation should be decided upon it should be performed well above the site of the disease and need not always necessarily be a disarticulation of the joint above the malignant condition but it must be pointed out that local recurrences in a stump are not unknown and these are usually very distressing

Although radiological evidence is not always final, in conjunction with the biopsy picture studied by competent pathologists I am strongly of the opinion that amputation affords the best results

radio-sensitive and the requisite palliation can be secured with small doses of deep X ray but though in spite of treatment the course of the disease is usually measured in months, it occasionally develops much more slowly and at least in one such case (a femoral tumour which involved the knee) amputation was worth while

(2) *Myelomatosis* This again though generally multiple is sometimes solitary, at *any rate for a time Though moderately radiosensitive, it may very occasionally* call for amputation.

(3) *Osteogenic Sarcomata* For years these tumours have been treated by amputation and the results are more favourable than is usually believed Amputation is

FIG 16. Radiograph shows extensive erosion of calcaneum. Note the soft-tissue swelling
(*Reproduced by kind permission of The Editor Journal of Bone and Joint Surgery. R. & S. Livingstone*

strongly favoured as an immediate operation. The real difficulty is one of diagnosis and this has been emphasized by Platt Brailsford, Cade and others They point out that neither clinical, nor histological nor radiographic appearances are infallible No X ray signs pathognomonic of sarcomata are known but arteriography may often give a diagnostic indication (Santos) Brailsford concludes that early amputation does more harm than good by taking off limbs unnecessarily through a wrong diagnosis

Cade says that the results are so bad that pre-operative radiotherapy is better followed by surgery

There is no agreement as to the risks and advisability of biopsy There can be no denying that an amputation can be invaluable in saving a patient unnecessary pain and relieving him of an encumbrance which can only hasten

[illegible]

( ) *Malignant Melanoma* [illegible] amputation

( ) *Soft-tissue Sarcomata* [illegible] may be an indication for amputation although [illegible] of the opinion that wide excision should be attempted [illegible] In a personal communication [illegible] has quoted several cases of partial [illegible] of the scapula for fibrosarcoma in lieu of

FIG 18 Recurring osteochondroma which finally became malignant and for which an above-knee amputation had to be performed.

amputation giving a good functional result and reasonable freedom from recurrence

(7) *Secondary Tumours* These have to be treated as individual problems and on the whole rarely justify amputation except in those cases in which deposits cause pathological fractures A hypernephroma may not infrequently require an amputation

(8) *Paget s Disease* complicated by a fracture at the site where sarcomatous changes have taken place will require an amputation well above the lesion These cases occur in elderly patients and amputation gives them an opportunity of becoming ambulatory again

Cases are not unknown where undoubted positive findings at a biopsy of an osteogenic sarcoma have survived for ten to fifteen years

(4) *Chondrosarcomata* are an indication for amputation They seem to be the most usual indications for hindquarter amputations owing to their predilection for the pelvis

FIG. 17 Uniting pathological fracture of lower third of femur Considerable loss of bone substance Medial displacement of lower fragment Biopsy showed that the cause of the fracture was an osteogenic sarcoma. Disarticulation of hip

Case History

Mrs C D aged 42 In June 1950 the patient noticed a symptomless swelling of the left calf X ray revealed a simple ossifying chondroma arising from the upper tibia and local removal was performed the pathological report confirming the clinical diagnosis.

In November 1950 there was a recurrence in the left calf this time with pain and subsequent removal was incomplete owing to involvement of the deep muscles. On this occasion the pathological report indicated "well marked sarcomatous changes. She was transferred to hospital in March 1951 and a

[illegible]

Fig. 20 Charcot knee joint [illegible] with [illegible] The joint [illegible] after amputation

Case History

Mr. F. C., aged 70. The patient presented himself at hospital in January 19[illegible] with swelling and tenderness of the lower right thigh.

The X-ray picture showed a supracondylar fracture of the right femur with irregular rarefaction [illegible] adjacent bone. A biopsy produced an inadequate [illegible] but a [illegible] tive diagnosis of chondrosarcoma was made and he [illegible] transferred [illegible].

[illegible] ll marked Paget's disease in the other femur and it was [illegible] ely that this was an osteogenic sarcoma secondary to Paget's disease.

In Mar[illegible] above-knee amputation was performed which healed satisfactorily [illegible] discharged and readmitted as an emergency in February 19[illegible] d spontaneous fracture through the lower end of the femur at [illegible].

Once again X-ray [illegible] showed rarefaction around the fracture site and a second [illegible] was considered to be present. Amputation was again perform[illegible] above the growth and the stump healed, but a few weeks later he developed backache, girdle pain and retention of urine. The radiogram revealed secondary deposit in the fourth lumbar vertebra.

The possibility of two separate primary growths in this case cannot be completely ruled out.

6. **Deformities or Paralysis.** Gross deformity which has failed to respond to orthopaedic treatment may incapacitate a patient more than an amputation. Likewise extensive paralysis causing a flail limb, particularly with trophic ulcers, may be an indication for amputation.

(*a*) Paralysis of the Upper Extremity. The significant features which should be considered in advising an amputation of the upper extremities can be analysed under the following headings:—

(1) *Loss of Muscle Power* (analysis of the remaining muscles as to their suitability for making use of an apparatus).
(2) *Loss of Sensation* having regard to the presence of trophic ulceration and the vascularity of the skin as to suitability for toleration of an apparatus.
(3) *Amount of Movement and Stability* of the remaining joints, including range and power.
(4) *Condition of the Hand and Fingers.* In addition, the duration of the paralysis should be taken into consideration, more especially the amount of improvement which has taken place. Improvement which has ceased for a period of over three years can be regarded as stationary from a practical point of view.
(5) *Age and occupation* (or proposed occupation) of the individual.
(6) *Psychological outlook* of the patient. There can be no doubt that some patients with irrecoverable lesions do not accept amputation; others of a more robust mental and physical outlook cannot bear to wait and they accept an amputation as the quickest way back to earning a livelihood or carrying on a normal life.

Amputation of the arm may occasionally be assisted by an arthrodesis of the shoulder. In advising a below-elbow amputation, due regard should

with their usual activities since the First World War The damaged nerve has not recovered and the foot has gradually developed an equino varus deformity with painful corns and sometimes trophic ulceration A few have been treated successfully by wedge tarsectomies but a large number of them require amputation A below knee amputation is the usual and successful procedure

Lesions of the cauda equina associated with meningococeles or as the result of trauma, often cause trophic ulceration deformity and sepsis These cases can be treated by below knee amputation They heal well and are successfully fitted with artificial limbs

(c) PARAPLEGIA A few long-standing paraplegics from the First World War have undergone above-knee amputations These cases have been wisely relieved of their useless irrevocably paralysed limbs and their lives have been made more tolerable

(d) INFANTILE PARALYSIS Many congenital deformities and cases of infantile paralysis of the lower limb with shortening do not necessitate amputation as the limbs can be fitted with appliances A deformed short limb becomes an acute problem to an adolescent boy or girl They frequently seek advice because of the cosmetic appearance of the limb In the upper limb amputation should not be resorted to where sensation and some function remain. In the lower limb it is necessary to assess whether an amputation or an artificial limb which will conceal the deformity will give the best functional results Extension limbs obviate an amputation and restore the cosmetic appearance

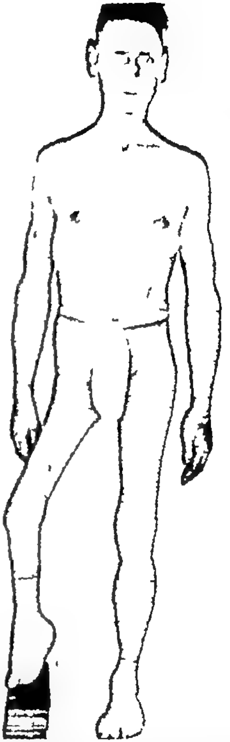

FIG 23 Flail leg and foot from long standing case of infantile paralysis. Severe shortening trophic changes and painful ulceration. Above knee amputation

General Considerations for Amputations

Surgical text books have perpetuated operative techniques in amputation which are now obsolete In pre-anaesthetic and pre-antiseptic days amputations were the chief operations of surgery In those days speed was the main consideration To-day as in all fields of surgery speed is not usually of such great importance It is more important to concentrate on surgical detail so that a better functional limb will be produced To-day in each case the surgeon plans an optimal level for the incision and the type of flaps to be used He should also however have a knowledge of the type of artificial limb which

be paid to the muscle power of the flexors to enable the prosthesis to be used actively A small amount of assisted flexion can sometimes be supplied by *means of a thong from the opposite shoulder to the forearm of the artificial* apparatus

The condition of the skin should be given a prominent place in the decision In amputation above the elbow it is important to recognize that the deltoid

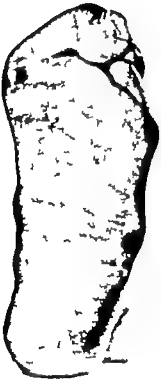

FIG 21 Sciatic lesion, trophic ulceration; deformed painful toes. Below knee amputation

FIG 22 Paraplegic patient from 1914–18 War with suprapubic cystotomy and high double above-knee amputation.

muscle need not be very powerful or even acting if the remaining muscles and internal rotators are acting It generally happens that some degree of periarticular adhesion of the shoulder fixes the shoulder while the power of the remaining scapular muscles can move the apparatus On the other hand if the upper extremity is so paralysed that it cannot be abducted an amputation together with an arthrodesis of the shoulder should be considered

(*b*) PARALYSIS OF THE LOWER EXTREMITY A number of cases present themselves periodically with irrecoverable nerve lesions of the lower extremity Some have proceeded

Control of Hæmorrhage After the patient is anæsthetized and on the operating table a tourniquet is applied as routine unless the vessels are known to be sclerosed and it is particularly desired to see how much bleeding occurs from the amputation site

The use of the tourniquet is advocated when amputating for trauma but in a case of a neoplasm or acute infection pressure bandaging for exsanguination should be avoided as it may be a factor in causing metastasis of growths or spread of infection

When there is vascular disease trauma to a vessel by a tourniquet may increase the seriousness of the vascular lesion by damaging the intima of the vessel Nevertheless many surgeons use the tourniquet when such conditions are present and consider the risk to be purely theoretical

Digital pressure on the main vessel is an alternative Incomplete occlusion of arteries and veins by inefficient compression causes difficulty in securing hæmostasis A trained assistant can control hæmorrhage by digital pressure for some minutes in higher amputations while the artery is being tied at the site of amputation

In high amputations of the thigh the main femoral artery should be isolated and tied as the first step in the operation while in shoulder amputations the subclavian artery should be ligated through a special incision below the clavicle This is not a difficult procedure as the pulsation can be felt easily

Tourniquet In the arm a pneumatic tourniquet is used and in the leg a new ½ in soft rubber tubing tourniquet or a simple Esmarch s bandage Samway s anchor tourniquet for the thigh is popular but it requires practice to apply efficiently It is small and light simple to apply and remove, and has no complicated mechanism which can become faulty the tighter the rubber is applied round the limb the more securely does the cleat hold The cleat fastens equally well at any point along the length of the rubber and does not cut it A second handle was added to Samway s cleat by Max Page to enable the operator to grasp the metal cleat during the operation

Tissue damage may result at the constricting ring of the tourniquet sometimes causing a chronic tourniquet ulcer and it is therefore always advisable to have a protecting pad such as a towel, between the skin and the tourniquet

The limb is either exsanguinated by applying an Esmarch s tourniquet over the sterile towels, and the tourniquet applied as high as convenient over a triangular bandage clear of the towels or the limb may be elevated for two minutes in order that the blood may gravitate It is important not to keep the limb elevated too long as in those circumstances vaso-constriction may occur When the tourniquet is applied and the limb lowered vaso-constriction passes off and the tourniquet may be ineffective

THE FINAL PREPARATION of the patient is carried out as for any other major orthopædic operation. In emergency operations the routine pre theatre technique of three days preparation has of necessity to be omitted but the usual theatre technique must be strictly adhered to For most amputations the patient is placed in the dorsal position on the operating table

Sandbags are placed as required and the tourniquet is applied as already described During the application of the tourniquet the end of the limb to be amputated is elevated and held at a convenient level by a non-sterile dresser At this stage all ward towelling and dressings are removed and the skin is finally prepared

Cleansing of the operation area proximally and distally as far as is deemed necessary is carried out as follows the first application to the skin should be of cetavlon the

will be supplied It is a matter of fine surgical judgment to decide the type of amputation which will ensure on the one hand that all infection will be eradicated and on the other hand, that a satisfactory functional prosthesis can be fitted to the patient

The following tables give results of a survey of patients fitted with artificial limbs at Roehampton (1945–50 Magee *et al* 1951) —

Reasons for 287 arm amputations and their age incidence

Age in years	Trauma	Osteo-myelitis	Congenital	Tuberculosis	Vascular	Diabetes	Other diseases	Unknown causes	Total cases
Under 11	5	0	31	1	0	0	0	10	47
11–20	19	0	12	1	2	0	0	5	39
21–30	33	0	8	0	0	0	2	8	51
31–40	41	2	6	0	1	0	2	8	60
41–50	34	0	5	1	0	0	2	14	56
51–60	14	0	2	1	0	1	4	5	27
61–70	2	0	1	1	1	0	0	2	7
Over 70	0	0	0	0	0	0	0	0	0

Reasons for 1,658 lower limb amputations and their age incidence

Age in years	Trauma	Osteo-myelitis	Congenital	Tuberculosis	Vascular	Diabetes	Other diseases	Unknown causes	Total cases
Under 11	12	7	13	2	5	0	6	43	88
11–20	38	15	9	12	12	0	20	33	139
21–30	69	34	4	19	21	0	33	75	255
31–40	127	39	9	28	34	4	42	99	382
41–50	99	41	16	23	68	4	48	61	350
51–60	87	16	1	16	70	15	39	38	282
61–70	34	22	0	7	46	7	16	17	149
Over 70	3	1	0	1	5	0	3	0	13

Methods used in Amputating a Limb

Preparation of the Site of Operation. Two days before the operation the part and its surroundings are shaved The area involved varies with the site of amputation but it is customary to include the groin for leg operations and the axilla for arm operations Should the amputation be in the proximal segment of the limb the area shaved must be extended to the waist and chest respectively

The skin is thoroughly washed and scrubbed with soap and water then rubbed with ether soap spirit and finally with methylated ether The limb is wrapped in sterile towels which are bandaged securely in place On the following day the skin is again washed with ether soap swabbed with spirit and then painted with tincture of merthiolate 1/1000 and wrapped in sterile towels On the day of the operation a further application of merthiolate is made and the limb is covered with sterile towels which will be removed in the theatre

clipped around the limb Any further towels may be used to ensure that the whole operating field is adequately protected

Method of Dealing with Blood-vessels After all blood vessels have been clamped with small delicate curved Mayo-Ochsner s artery forceps which I have found most suitable the vessels are ligated as described

The order of ligaturing these vessels is important and should be from the periphery to the middle. The middle and deeper blood vessels are thus the last to be ligatured in an unobstructed operative field It is best to employ catgut sutures size 2 for the larger vessels and size 00 for the smaller vessels

After all known and visible cut vessels have been ligatured the tourniquet is released Dry packs are then inserted in the operation field and the remaining blood vessels are caught up and ligatured

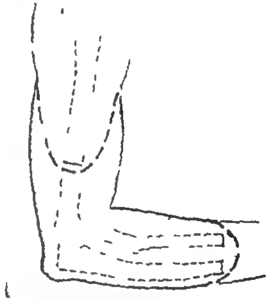

Fig 23 Amputations of the upper extremity showing site of bone section, line of skin incision and ultimate shape of stump.

Closed Amputations

Amputations or disarticulations can be performed by the closed method or the open guillotine method The former is ideal but it should not be performed through a septic field

The closed method can be carried out by procedures which differ in the manner of the division of the skin and muscle The names of the various flap methods circular elliptical or racket amputations are classical and to a large extent self-explanatory

The Flaps. For all practical purposes one method of amputation is used to-day that of flaps. This method was used as long ago as the year 1679 by Lowdham an Exeter surgeon The decision as to which method should be employed must depend on circumstances particularly if there is laceration of the skin In the case of re-amputations flaps may be two of equal size two of unequal size or a single flap

The flaps are usually anterior and posterior but can if necessary be lateral or intermediate between these two positions As a rule they are made of equal length but there is no radical objection except in vascular cases to unequal flaps, in which case the anterior should be slightly longer Flaps should be rectangular or broad U shape

The accepted rule is that one single flap should be in length one and a half times the diameter of the limb at the level of amputation This is too generous a quantity of skin and applicable only as an examination exercise It is not necessary in the living subject where the skin is pliable and elastic and has good vitality Flaps which are too large lead to the formation of pouches in which serum and blood collect and can easily become infected On the whole the shorter the flap the better its nutrition If the stump heals with large flaps the skin becomes infolded during the wearing of an artificial limb The opposing skin surfaces sweat and develop eczema and intertrigo from contact of the folds

second of spirit and the final one of a solution of merthiolate Any preparation required on the diseased or traumatized area should be carried out at this stage before the actual towelling up takes place

With the limb still elevated, a large sterile sheet is placed across the operating table covering the sound limb and extending well above the prepared area At this stage in amputations of the lower extremity it is useful to place a specially prepared and sterilized block on the table above the level where it is proposed to amputate

In almost all amputation operations the patient lies on his back and a general anaesthetic is the method of choice The limb is placed across the sterile triangular block of wood in such a position that the block will support the limb just proximal to the site at which it is proposed to amputate the limb The surgeon stands on the side nearest

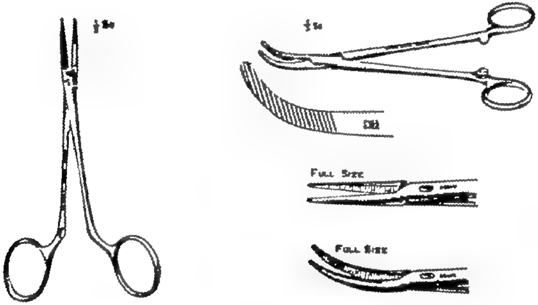

Fig 24. Soutell's large artery forceps for clamping large blood vessels, and small pointed straight and curved artery forceps for smaller vessels.

to the limb which he is about to amputate and his assistant takes up a suitable position opposite to him

The instrument table is usually placed in a convenient situation adjacent to both the surgeon and his assistant while the theatre sister stands next to the instrument table

Instruments required are the usual basic set with ordinary *scalpels* and should include an amputation saw a Gigli saw bone cutting forceps and a rasp for smoothing off the bone ends

After completing the towelling and when the limb has been placed on the table the block can be placed more accurately so that it will steady the limb and keep it elevated at a comfortable level during the operative procedure

A sterile towel is then placed around the limb—the lower edge of the towel should extend to the most proximal line of the prepared area The towel should be fixed with a clip A second towel is draped above the first and secured a few inches higher than the level of the first Thereupon a second sheet is placed around the limb—the lower edge being fixed at a higher level than the second towel—and arranged in such a way that the major portion of the sheet is protecting the side of the operating table This is

clipped around the limb Any further towels may be used to ensure that the whole operating field is adequately protected

Method of Dealing with Blood vessels After all blood vessels have been clamped with small delicate curved Mayo Ochsner's artery forceps which I have found most suitable the vessels are ligated as described

The order of ligaturing these vessels is important and should be from the periphery to the middle. The middle and deeper blood vessels are thus the last to be ligatured in an unobstructed operative field *It is best to employ catgut sutures size 2* for the larger vessels and size 00 for the smaller vessels

After all known and visible cut vessels have been ligatured the tourniquet is released Dry packs are then inserted in the operation field and the remaining blood vessels are caught up and ligatured

Closed Amputations

Amputations or disarticulations can be performed by the closed method or the open guillotine method The former is ideal but it should not be performed through a septic field

The closed method can be carried out by procedures which differ in the manner of the division of the skin and muscle The names of the various flap methods circular elliptical or racket amputations are classical and to a large extent self-explanatory

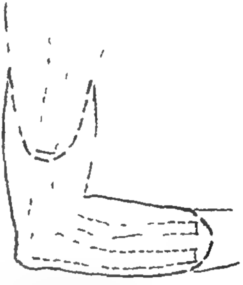

Fig 33. Amputations of the upper extremity showing site of bone section, line of skin incision and ultimate shape of stump

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The total perimeter of the skin edge in the flaps whether they are circular or not should equal the diameter of the limb They should not exceed one and a half times the diameter at the level of the bone section

Circular and elliptical methods are seldom used in Britain although they have their merits Racket amputation is employed particularly at the hip shoulder or metacarpo phalangeal joints because it enables the main vessels to be ligated at the beginning of the operation, and so helps to control hæmorrhage

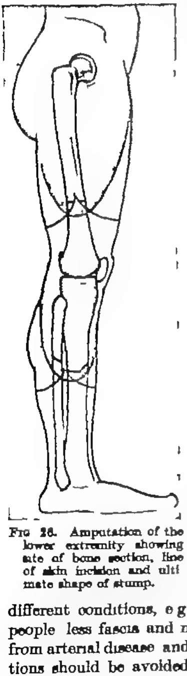

Fig 26. Amputation of the lower extremity showing site of bone section, line of skin incision and ultimate shape of stump.

The nutrition of a flap is of primary importance and in planning any amputation much respect should be paid to the future vitality of the skin. There is no doubt that a long flap is unsatisfactory especially if it is turned sharply over the end of a bone and sutured some distance above the end of the bone on the opposite side The nutrition and innervation is poor and a flap so planned, if it does not become gangrenous soon after the operation is certainly not likely to stand up to limb-wearing

In the past circular flaps have been used, and in some respects they are ideal except that dog-ears always result Even then it is a simple matter to trim these unsightly ends with a pair of scissors It may be advisable to modify a circular flap because of oblique and vertical scars on the limb in which case it will be necessary to have an oblique or vertical incision to make the flap more manageable according to the size of the limb Such flaps are converted into antero-posterior or lateral flaps of approximately equal size

The Method of Incision. Flaps should be cut from without inwards The scalpel should not be small and should be held in a manner that gives perfect control of the blade Though the flaps should not be fashioned too long it must be remembered that during the operation, they should be fashioned longer than is necessary for they can never be lengthened. It is a simple matter to trim them appropriately at the end of the operation

Fascia and muscle only should be included in the base of the skin flap so as to ensure the necessary blood supply and nutrition of the flap This of course will vary under different conditions, e g age arterial sclerosis etc In young muscular and healthy people less fascia and muscle can be left than in the case of older patients who suffer from arterial disease and whose blood supply therefore is more precarious Large dissections should be avoided they injure important blood vessels and rob the skin of its deeper blood supply

Retracting Musculature. It was formerly taught that large metal muscle retractors were essential for amputations I never use one now They are cumbersome and the amputation can safely and accurately be performed without them

If the surgeon desires a muscle retractor an efficient one can be made from a piece of *stout calico with one slit in the side for the thigh and upper arm amputations* and two slits for the leg and forearm. The edges of the cloth should be well hemmed. These calico retractors can be sterilized with the instruments by boiling. In calico retractors with two slits the tongue of the material can be passed between the radius and ulna, or the tibia and fibula.

The Stumps. The best stumps are those which are moderately conical provided they have an adequate tissue covering. The thin pointed lead pencil type of stump is painful and tender, easily breaks down and very often requires re-amputation. In the elderly patient with wasted limbs a small covering of muscle is recommended. This gives the stump a much better opportunity to heal and also provides a firmer covering for the end of the bone. In the final stump the skin and subcutaneous tissue should be mobile over the end of the stump. A stump which is too bulky is more difficult to control within the artificial limb. The mobile pad of subcutaneous tissue is redundant, yet

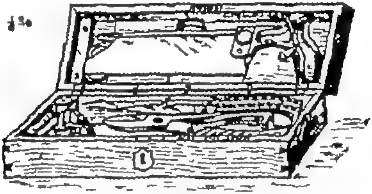

FIG. 27. Amputation saw and bone cutting forceps. Syme's amputation knife. This is not now commonly used.

requires additional accommodation within the socket. A striking exception to a large pad is in Syme's amputation.

The Section of Bones. This should always be a secondary consideration to skin section in *contra-distinction to emergency amputations*. That does *not mean that the* bone should be unnecessarily sacrificed for a stump of ideal length, but it should be appreciated that an inch or two less of bone in a well healed stump produces a far better stump than an inch or two more of bone which is poorly covered. It cannot be too strongly stressed that a tapering stump often gives the patient the impression that it is protruding through the skin, and indeed, sometimes it does.

It has not been proved that there is any particular advantage in fashioning a periosteal cuff. No attempt should be made to remove or separate the periosteum except in the case of the tibia. The bone should be sawn through cleanly. The saw cut is commenced by steadying the saw against the thumb. By drawing the saw towards oneself with a few light strokes, a groove results in the bone. While the assistant steadies the limb the surgeon grasps it with his left hand immediately above the site of section and continues to saw steadily through the bone. The assistant should be instructed to hold the limb in such a way *that he exerts slight horizontal traction* with a tendency to backward displacement as the gap in the bone deepens. If this is not attended to, the blade tends to bind between the two cut ends. Spikes and splinters of bone should be

filed down neatly and no periosteal tags left All protuberant edges should be carefully filed and bevelled e g the crest of the tibia Experience has shown that in certain situations i e on the postero internal aspect of the femur spurs will almost always form. There is no advantage in removing a cuff of periosteum from the end of the bone or leaving a long periosteal flap to be sutured as a protective covering over the bone The projection of a bone of small diameter such as the end of the radius or the fibula, is undesirable and these bones should always be shortened. In the forearm the radius and ulna should be of equal length while in the lower leg the fibula should be made ¾ to 1 in shorter than the tibia

Occasionally quite a large artery within the medulla of the bone is divided Such arteries bleed freely It is unwise to crush the bone in order to occlude the vessel, as this may splinter the bone A slight tap with a blunt instrument will very often occlude it Bone wax should not be used as it is an unnecessary foreign body but a muscle tab placed over the bleeding point is often effective

The Section of Nerve Odier in the beginning of the nineteenth century first described enlargements or swellings which developed on the distal end of a proximal segment of a peripheral nerve after partial or complete division He started the practice of injecting nerves with absolute alcohol and sectioned them just below the injected area. There is no doubt that this is harmful. Nerves should not be crushed or ligated The careful studies of Huber and Lewis have shown that the perineural flap method as suggested by Corner the swing-door or reverse V operation and the crush and tie procedure are incapable of preventing the formation of neuromata Moreover one should not tie a nerve filament in with an artery, it is a direct cause of painful convalescence

It is clear that at present there is no means by which the formation of a terminal end bulb to a sectioned nerve can be prevented. The nerve should be cut through cleanly with a sharp scalpel. It should not be crushed or injected, or treated in any way It is wise to shorten a nerve by careful section, so that the bulb will eventually form in a protected plane amongst the muscle bellies Pressure on a healthy nerve trunk by an artificial limb does not cause pain but pressure on a nerve bulb may produce it Pain in end bulbs often occurs when suppuration has been present in the limb In such cases it is certainly not desirable to pull the nerve trunk down

In above-knee amputation there is no pressure between the socket nerve bulb and the bone because the modern limb is ischial bearing It is never wise to ligature even a large nerve when it is bleeding because the hæmorrhage will stop However in the case of a large nerve like the sciatic the artery may be separated from the nerve and ligated with fine thread Prevention of post-operative pain in all stumps is important because in a sensitive highly intelligent individual this may well be the beginning of a series of incurable painful sequelæ

There are certain other methods of amputation which have a limited application or are of historical interest —

Circular Amputations

(a) **Guillotine.** A circular cut around the limb and through all the tissues including bone In the Second World War this was the routine method in the German Army

The flapless or guillotine amputation had been used for centuries It became popular in the 1914–18 War the object being to save life Since it was not intended to fit a prosthesis to a provisional stump of this nature this did not concern the limb maker and the surgeon needed to be governed only by surgical considerations in his choice of site and technique The wounds did not heal without infection and the surgeon considered it wise to amputate as low as possible to preserve unsoiled tissues which might be dealt with at the final amputation

All amputations should of course be done through uninfected and uninjured tissues but there is no need to go high above the level of the infection Experience in World War II showed that bone infection quickly disappeared with adequate drainage and all amputations afford excellent drainage In fact there is no better way of draining all the tissue planes than by cutting them across transversely Furthermore in the last years of the war we had not only blood transfusions at our disposal which improved the general condition of the patient but also with the aid of penicillin we were able to combat infection and the patient consequently improved rapidly This of course does not in any way eliminate the important necessity of adequate drainage

FIG 28 Guillotine amputation in popliteal fossa. Note jagged skin ends and large surface of exposed muscle

In the true guillotine amputation which is not a chop amputation but a circular one the surgeon cuts through the skin and allows it to retract cuts through the muscle and fascia allowing them to retract then cuts through the bone This produces an inverted cone with bone at the apex end and retracted skin at the base It is necessary therefore to apply some form of traction to the skin to prevent too much retraction A second amputation at a more favourable site and time will have to be done Traction on the skin may help to prevent the ultimate length of stump being shorter than the ideal.

The difficulty of maintaining traction on stumps of casualties who have to be moved several times and transported over considerable distances is great but in practice even in those cases which had traction applied and were seen about three weeks later the bone was found to be protruding Granulation soon developed and we were left with stumps which had no skin to close them

To put on traction and maintain it even after a guillotine amputation of two weeks standing is a difficult procedure Taking into consideration the evacuation of cases from theatres of war even when modified Thomas s splints were used with graduated traction by turn buckles or when buttons and sterilized tin with steel wire were used, no satis factory method of traction in a guillotine amputation was found If the wounds are left open and flaps have been cut infection settles down and traction is not necessary In modern warfare there is no means of applying traction effectively in the field and in the guillotine amputation this is necessary It is always worth while saving skin. Skin is not dangerous from the point of view of gas gangrene The flaps can be closed subsequently in a reasonable time and the case may not require secondary operation If bone injury occurs and good skin is available on one side it is important to save this skin

FIG 20 Above knee guillotine amputation with adherent scar and ulceration. Note effect of piston action. Re-amputation.

The level of bone injury or infection should determine the level of the amputation not the level of the wound If there is viable skin even when it is irregular in shape it should be preserved at all costs Skin grafting is not necessary, or good if normal skin can be preserved Normal skin stands up to pressure and the contraction which occurs in stumps much better than grafted skin

Most remodelling operations follow on guillotine amputations Again it should be stressed that the nerve should be cut transversely in such a way that it will lie in a muscle plane No vessels in an amputation nerve need be ligated not even in the sciatic nerve Alcohol should not be injected nor should formalin or electric coagulation of the nerve or artery be considered. They do not prevent nerve bulbs Drainage when skin flaps are cut is adequate if the skin is lightly sutured healing is much quicker and the raw end of the bone is not left protruding It is quite safe to do an amputation of this type even

when the infection is of some standing In an early amputation where infection is recent skin flaps should be cut and no stitches should be inserted

(*b*) **Cuff** A circular cut is made through the skin and subcutaneous tissue These layers are then pulled up and a circular cut is made through the muscle at a higher level The muscle is then in turn drawn up to allow bone section at a higher level This method leaves a bulky and unstable stump in which the skin is puckered and indrawn I believe this method should also become obsolete

(*c*) **Transfixion** In this method a knife is plunged through the soft tissue of the limb and drawn from within outwards Some surgeons still use this method after they have made their skin flaps particularly in situations where tendons predominate e g the forearm I believe there is nothing to recommend it

(*d*) **Racket** This method is valuable particularly in situations where vessels can be ligatured as a first step in the operation i e the hip or the shoulder or in cases where digits require amputation because it has the value of allowing a scar to be made in a situation where it will be free from pressure and where it will not interfere with movement It also enables some of the skin of the amputated segment to be utilized

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CHAPTER III

STANDARD AMPUTATIONS

The sick man might conquer his disease with the help of the physician
HIPPOCRATES

General Considerations Concerning the Length of a Stump

It has been found by clinical observation that there is an optimum level for amputation for each segment of a limb Over the past thirty five years stumps have been studied continuously in conjunction with the artificial limbs that were thought mechanically the best and gave the best functional results

The length of a stump has a direct bearing on (1) the functional power of the stump (2) accuracy of control and (3) the nutrition and vitality of the skin

1 **The functional power of the stump** is proportional to its length and to the muscle volume of the segment It depends on the length and the site of insertion of the essential remaining muscles e.g in a below knee stump the power is dependent upon the muscle power of the quadriceps while the length of the stump below this will not materially affect the leverage

On the other hand a short above knee stump below the insertion of the ilio psoas muscle will not have as much power of flexion as one which has the added substantial leverage of the remaining rectus sartorius and tensor fascia femoris muscles

Although the ilio-psoas is the chief flexor no more bone is required in a stump than is sufficient to form a satisfactory lever The retention of more bone than is necessary is a positive disadvantage both surgically and mechanically

2 Accuracy of control depends upon the insertion of the essential remaining muscles in the lever e g in the forearm the biceps and brachialis muscle in a below knee the quadriceps and in the thigh the adductors and extensors

3 Skin nutrition and pressure are important factors and it has been found that longer stumps do not maintain their vascularity as well as shorter stumps Surgically all long stumps other than disarticulations at the knee develop circulatory defects sooner or later When the nutrition becomes poor the stump becomes discoloured and painful and re-amputation at a higher level will be required especially in below knee and below elbow stumps

Disarticulations at the junction of the trunk and limbs are undesirable because (1) they allow no leverage and offer little grip for a limb to be suitably adapted (2) there is no accuracy of control from lack of a lever and (3) the natural contours of the body are altered and limb-fitting becomes less æsthetic In general disarticulations through the distal joints of necessity result in bulky and club-shaped stumps which are difficult to fit æsthetically In children however it may be advisable for anatomical as well as psychological reasons to advise disarticulations especially where the lower extremity is affected

Amputations of the Upper Extremity

The importance of the hand is due to its tactile sensibility Its grasping power and the irreparable loss sustained by its removal render the greatest caution necessary lest

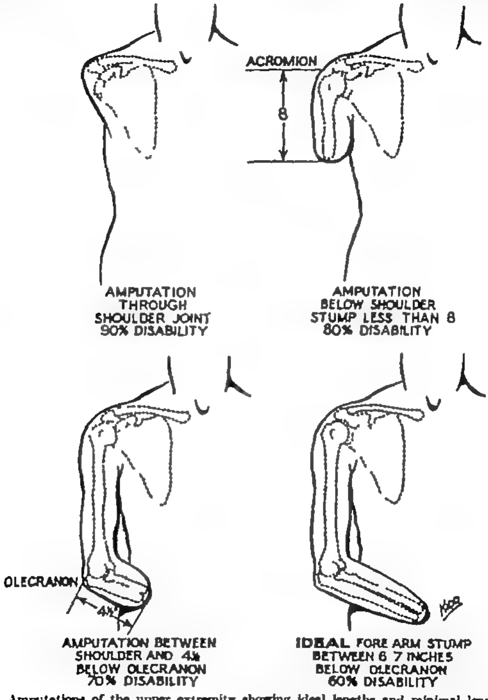

FIG 30. Amputations of the upper extremity showing ideal lengths and minimal lengths with assessment of the percentage disability [A J Craft Annals of Roy. Coll. S rg. Eng.

we should remove a single digit or a portion of one that might be saved. No prosthesis has yet been devised which compensates for the loss of sensation and prehensile function caused by the amputation of a hand Hence a conservative attitude in regard to amputations of the arm and hand should always be adopted

After amputation of the upper arm the adapted conical socket of the prosthesis is fixed to the trunk by special body attachments These enclose the anterior thoracic wall and the scapular region It is evident that in order to obtain the optimum transmission of movement i e forward backwards or outwards it is essential to have a fairly long humeral stump The power of the lever will not be of great value unless the amputation is at or below the middle of the arm The apparatus retains its position much better and its suspension from the shoulder is more secure, if the stump is filled out by the head of the humerus and, at least its anatomical neck Apart from this the normal contour of the shoulder is preserved , hence the superiority of the prosthesis for long arm amputations compared with disarticulation of the shoulder or short arm amputations

When the stump of the humerus is long enough to be used the pressure sustained by it in the transmission of movements to the apparatus is taken by the anterior posterior and outer surfaces There is no pressure on the end A terminal cicatrix is therefore no inconvenience if it is not adherent to the bone and a circular amputation or one of equal antero posterior flaps may be employed according to taste The same applies to amputation of the forearm where the stump executes hinge movements in the sagittal plane and there is no terminal pressure Here it is of considerable importance to see that the stump is sufficiently long to give adequate control to the apparatus and enable it to be better enclosed yet it should not be so long as to suffer from vascular insufficiency

Amputation at the wrist allows in certain special actions direct use of the stump without an apparatus, e.g in pushing an object or in maintaining it in position by pressure The ends of the bone must therefore be well padded by palmar skin and the cicatrix should be dorsal An anterior flap or one of its modifications is for this reason to be preferred

The most useful function will be obtained if —

(a) The arm amputation is carried out in the lower third of the humerus 8 in (20 to 22 cm) from the tip of the acromion

(b) The forearm amputation stump measured from the tip of the olecranon should be between 6 in. and 7 in. (15 to 18 cm) in length

(c) The hand and fingers are dealt with on the lines suggested in Chapter V e.g , by giving special consideration to length mobility and muscle power of the digits

In addition to amputations various orthopædic procedures may also be adopted according to such problems as may present themselves in particular cases In a flail shoulder and a flail and useless whole upper extremity arthrodesis of the shoulder enables the stump to be moved In a forearm amputation complicated by a stiff elbow a pseudo arthrosis in the lower part of the arm will give improved limb function particularly when fitted with a suitable prosthesis

Much of the previous discussion concerning stumps of the lower extremity applies equally to those of the upper extremity particularly comments referring to the defects of long stumps Here again we require for surgical and prosthetic reasons a stump which is of sufficient but not excessive length to act as a lever and to control the limb Scars should be placed in such a position that they will not be subjected to pressure but in the case of arm stumps in contradistinction to those in the leg the scars to avoid pressure may be terminal and transverse

Subcapital Amputation of the Humerus

Whenever possible the head of the humerus should be preserved as it provides a well shaped stump on which to fit an artificial limb and the contour of the shoulder is not lost

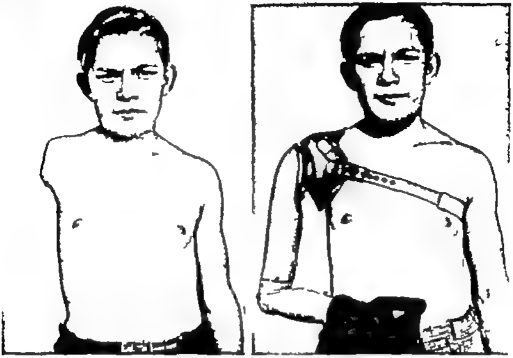

FIG 31 Subcapital amputation of right humerus. Artificial limb applied. Note preservation of contour of the shoulder

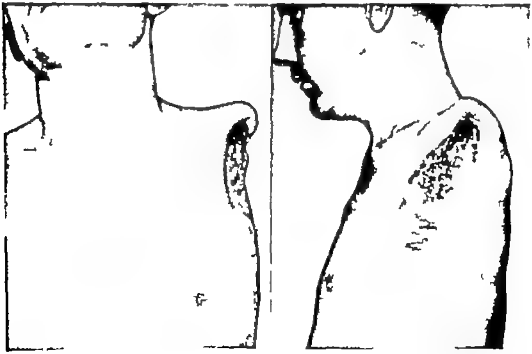

FIG 32. Disarticulation of shoulder with pigmentation of the cavity Note unsightly appearance due to overhanging acromion. Loss of contour and consequent difficulty in fitting

When the head of the humerus is removed the acromion and coracoid processes become prominent and the fitting of a prosthesis is rendered difficult because of the tenderness of local pressure points. The classical anterior racket incision is generally applicable and the axillary artery should be tied as one of the early steps of the operation. All the nerves should be shortened. It is specially important to avoid unnecessary trauma to the brachial plexus.

Arm. As previously stated the ideal length of stump is 8 in (20 cm) from the tip of the acromion with a minimum of 5 in (12 cm). Less than this can occasionally be utilized with advantage by dividing the lower fibres of the posterior axillary fold (latissimus dorsi muscle) to enable the socket of an artificial limb to remain around the stump during movements.

Any amputation stump which ends less than 2 in (5 cm) above the elbow joint is too long for the fitting of a useful prosthesis. Equal antero posterior or circular flaps can be usefully employed in the upper arm. The skin is elastic and freely movable and unorthodox flaps can be readily fashioned in the case of scarring of the arm. The muscles should be cut flush with the bone and the deep fascia and skin neatly approximated.

Technique of Above-elbow Amputation

(1) A pneumatic tourniquet is applied as high as possible to the arm. (2) Equal antero posterior flaps are cut to give a stump 8 in in length from the acromion. (3) The initial incision is made down to the deep fascia but not through it. (4) Skin is then reflected with the superficial fascia. (5) The soft tissues are divided to the bone and the humerus is sawn across at right angles to its length. (6) The vessels are tied off and the nerves pulled down and shortened by an inch. (7) The tourniquet is then deflated and any further bleeding controlled either by ligature or by deep bites of catgut. (8) The fascia is sutured by interrupted catgut and the skin by interrupted silkworm gut. (9) Dressing and stump bandage are applied as described below.

Elbow. Amputation through the elbow joint leaves a broad stump difficult to fit and should rarely be considered for a permanent amputation. The artificial elbow mechanism is cumbersome, bulky, and difficult to manipulate.

Forearm. *Disarticulation at the wrist-joint or amputation immediately above it gives* an unsatisfactory stump with poor circulation and one which is difficult to fit with a prosthesis.

Amputation through the wrist is sometimes advised with the claim that thereby the power of pronation and supination of the forearm is preserved. In actual fact this is not the case, as the socket of an artificial arm which fits the stump snugly will obviously prevent this movement. Occasionally a re amputation above the wrist can be avoided by preserving the metacarpals with a perfect wrist, as the remaining stump can then be made useful, retaining movement and sensation. A working hand is easily made with a fixed wrist as in the case of a forearm amputation.

The ideal forearm amputation is to retain about 7 in of radius and ulna. The minimum lengths of these bones which allow good fitting are about 2 in below the insertion of the biceps tendon. It is important, however, to preserve the elbow joint at all costs if it is functioning normally.

Technique of Below-elbow Amputation

(1) A pneumatic tourniquet is applied to the upper arm. (2) Equal dorsal and volar flaps are fashioned to give a stump 7 in (16 to 17 cm.) long as measured from the olecranon. Care should be taken in positioning the arm to place it in supination on the arm rest and not to have any torsional strain on it below the elbow or the flaps after being cut are drawn into an oblique position by the elasticity of the skin The skin flap of the original incision should include the deep fascia. (3) The soft tissues are divided down to the bone and (4) both radius and ulna are sawn across by the same cut at the anatomical level (5) The vessels are secured, as before (6) The tourniquet is deflated and final hæmostasis secured (7) The fascia and skin are sutured as separate layers as before

Amputations of the Lower Extremity

The incidence of amputation in the lower extremity is much higher than in the upper extremity Diseases such as circulatory disturbances neoplasms injuries and deformities which have not yielded to orthopædic measures and require amputation are more frequent in the lower than in the upper extremity When considering amputation one is confronted by a different problem from that of the upper extremity The stump of the lower extremity will be called upon to carry the body weight in walking acting as a support and a lever whereas the upper extremity will not be called upon for weight-bearing purposes but will have to perform numerous other complicated functions

It would be ideal if the stump of the lower extremity could carry the whole body weight on its end. Nature intended the long bones of the body to function in this way but in the modern amputation cases in Britain few stumps are called upon to be end bearing whereas in the United States and Canada this is more common From the physiological anatomical and surgical points of view end bearing stumps are the more desirable Physiologically they have the longest levers the greatest muscle volume and therefore provide greater power Anatomically it is undesirable to have to cut through muscles and sever them from their insertions and surgically it seems better to disarticulate through a joint than to have to sever the bone higher up

A study of a large number of cases has shown however that because of circulatory trouble these end bearing stumps have not stood the test of time In the past thirty years about 20 000 thigh amputations have been seen and examined at Roehampton It has been found that in stumps of over 12 in (30 cm) in length in thigh amputations (this includes transcondylar and Stokes Gritti amputations) circulatory disturbances occurred in about 55 per cent while stumps under 12 in (30 cm.) in length on the other hand, are not suitable for fitting with end bearing prosthesis It has been stated by Kelham that of about 400 thigh amputations fitted in this country only about four are fitted with the type of prosthesis used in Canada Furthermore it has been stated that at Roehampton excoriations in below knee amputation stumps do not occur because the weight is taken on the ischium At Roehampton below knee stumps are fitted as follows —

(a) Tibial bearing	7 5 per cent
(b) Partial tibial partial thigh bearing	20
(c) Mainly thigh bearing, partial ischial bearing	15 25
(d) Full ischial bearing partial thigh bearing	43 65

The suture line in an amputation of the lower extremity should be either terminal or posterior except of course in amputations of the foot, when it should preferably be anterior The muscles of the stump soon pull the scar line backwards and upwards when walking begins Tension in a scar if it is non adherent to bone is less when it is posterior

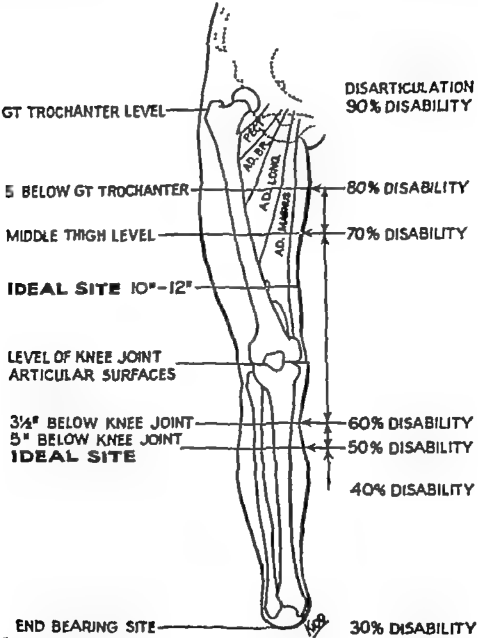

FIG 33 Lower extremity showing the ideal, and permissible, sites of amputation—standard evaluation of disability

[A J Craft Annals of Roy Coll. Surg Eng

than anterior Adherent scar tissue at the end of a stump should always be avoided as it will break down eventually

Above-knee Amputations

As has already been stated there are still divergent views regarding the necessity for retaining as much bone and muscle as possible There are those who consider that the longer the bone the greater the leverage Others maintain that as the psoas muscle is the chief flexor no more bone is required in a stump than is sufficient to form a satis

factory lever that the retention of more bone than is necessary for this purpose is a positive disadvantage both surgically and mechanically Statistics are produced to show that all long stumps other than disarticulations at the knee sooner or later develop circulatory defects which render re-amputation necessary The most satisfactory stump (in that from the surgical point of view it does not develop circulatory troubles and from the prosthetic aspect it forms an efficient lever) is one which measures 10 in (25 cm.) from the tip of the greater trochanter in a short man to 12 in (30 cm) in a man of average height For a very tall patient a stump not exceeding 13 in (32 cm) is permissible

This length of stump may also be arrived at from a different angle An amputation with the bone section performed 4 in (10 cm) above the adductor tubercle will give the correct length of stump in short to medium length femurs For instance if bone section is made 4 in. (10 cm) above the adductor tubercle in a femur 17 in (42 cm) long, the stump will be 11½ in (28 cm)—not too long surgically but giving ample clearance for any mechanism it is proposed to incorporate within the artificial knee piece

Fig 34 Posterior view of a satisfactory above knee amputation showing position of the scar in relation to the nerve bulb above it and the subsequent spur below it

(By courtesy of J E Hanger and C Ltd

The positioning of the scar upon an amputation stump is of considerable importance it should not be placed in a position in which it can be abraded by friction against the socket of the limb The ideal site for the scar is provided by an anterior flap of such dimensions that the resultant scar is transverse posterior and lying about 1½ in. (4 cm) above the extremity of the femur In this position it cannot become abraded by the socket of the limb nor can it be subjected to traction from the piston action of the stump within the socket as it would be were it situated terminally

Technique of Above-knee Amputation

(1) A tourniquet is applied as high up the thigh as is practicable (2) Equal antero-posterior flaps are cut designed so as to produce a stump 11 in (28 cm.) in length measured from the great trochanter The original incisions should include the deep fascia, and the flaps themselves are short compared with the old classical measurements (3) The soft tissues are divided to the bone with clean deep sweeps of the knife so that no ragged edges are left as the muscles retract (4) The femoral vessels are doubly ligated and all other visible bleeding points are secured The long saphenous vein requires a ligature of its own (5) The sciatic nerve is pulled down a little from the wound surface and cut across so that it retracts and care taken that any accompanying vessels are secured before the nerve disappears otherwise there may be an annoying source of hæmorrhage from an inaccessible point (6) The tourniquet is removed and final hæmostasis secured muscle ooze being controlled by large deep bites of catgut (7) The deep fascia is sutured with interrupted catgut and the skin with interrupted silkworm gut or nylon A drain is not usually required (8) Dressing of tulle gras gauze and two layers of cotton wool are applied and a firm stump bandage is put on to hold the dressings in position and maintain pressure

Amputations through the Condyles of the Femur

In the *London and Edinburgh Journal of Medical Science* Syme advocated a method of amputation through the condyle of the femur as especially suitable in cases of diseased knee joints He said that amputation at this site had certain advantages —

(1) The shaft of the bone being untouched there is no injury to the medullary cavity and hence no fear of inflammation of its lining membrane

(2) There is less risk of sequestration the cancellated texture of the epiphysis not being liable to sequestration

(3) Being close to the joint the muscles are cut through at the tendinous part, thus considerably diminishing the risk of retraction and consequent protrusion of bone

(4) A large broad surface of bone is left to bear the weight of the body and one which like the ankle-joint stump will round off and afford a comfortable pad over which the skin of the flap will play freely

All these reasons are surgical reasons given by a past master in the art, but some of them have now become obsolete For even as the surgeon has improved his art and surgery been made easier and less dangerous by modern methods the limb fitting surgeon also has made great strides The limb fitting surgeon states that the extra length is of no value from any point of view End bearing cannot be tolerated for long even by transcondylar amputations without harm resulting to the stump and circulatory disturbances occur sooner or later necessitating re amputation

Amputation at the Knee-Joint

The operation for amputation at the knee joint is over one hundred years old Its first great exponent was *Velpeau* who used a circular cuff which he closed in the sagittal plane In 1830 he collected and described fourteen cases These included the first recorded cases in America treated by *Nathan Smith* in 1824 *Stephen Smith* added ten more American cases to the literature in 1852 It was *Brinton* in 1868 who distinguished between amputation at the knee-joint and at the knee The latter term embraced all those procedures in which the condyles were cut and now includes the *Carden* operation of his day the osteoplastic operation of *Stokes-Gritti* the tendoplastic operation of *Callender* and the osteoplastic operation of *Perry Rogers* In 1850 *Skey* called this amputation a relic of ancient surgery when it had been revived and seemed justifiable to other surgeons Practised by *Fabricius Hildanus* and *Guillemeau* in the sixteenth and seventeenth centuries it had fallen into disuse until revived by *Horn Velpeau* and *Baudens* on the Continent *Nathan Smith* in America and *Arbuthnot Lane* in London

It is revealing to study the reasons why Skey did not think this a suitable operation He considered its use to be comparatively rare and for it to succeed the following conditions were essential —

(1) There should be abundant skin in front of the knee joint to make a long anterior flap

(2) The patella and articular surface of the femur should be healthy

These two conditions he says, exclude nearly every case of disease or accident If the joint is diseased and amputation is decided upon then obviously a thigh amputation should be undertaken If injured and the front of the knee is safe he says it may very likely be possible to amputate below the knee

factory lever that the retention of more bone than is necessary for this purpose is a positive disadvantage both surgically and mechanically Statistics are produced to show that all long stumps other than disarticulations at the knee sooner or later develop circulatory defects which render re-amputation necessary The most satisfactory stump (in that from the surgical point of view it does not develop circulatory troubles and from the prosthetic aspect it forms an efficient lever) is one which measures 10 in (25 cm.) from the tip of the greater trochanter in a short man to 12 in (30 cm) in a man of average height For a very tall patient a stump not exceeding 13 in. (32 cm) is permissible

This length of stump may also be arrived at from a different angle An amputation with the bone section performed 4 in (10 cm) above the adductor tubercle will give the correct length of stump in short to medium length femurs. For instance if bone section is made 4 in (10 cm) above the adductor tubercle in a femur 17 in (42 cm) long the stump will be 11½ in (28 cm)—not too long surgically but giving ample clearance for any mechanism it is proposed to incorporate within the artificial knee piece

FIG 34 : Posterior view of a satisfactory above knee amputation showing position of the scar in relation to the nerve bulb above it and the subsequent spur below it

(By courtesy of J E. Hanger and C Ltd

The positioning of the scar upon an amputation stump is of considerable importance it should not be placed in a position in which it can be abraded by friction against the socket of the limb The ideal site for the scar is provided by an anterior flap of such dimensions that the resultant scar is transverse posterior and lying about 1½ in. (4 cm) above the extremity of the femur In this position it cannot become abraded by the socket of the limb nor can it be subjected to traction from the piston action of the stump within the socket as it would be were it situated terminally

Technique of Above-knee Amputation

(1) A tourniquet is applied as high up the thigh as is practicable (2) Equal antero posterior flaps are cut designed so as to produce a stump 11 in (28 cm) in length measured from the great trochanter The original incisions should include the deep fascia and the flaps themselves are short compared with the old classical measurements (3) The soft tissues are divided to the bone with clean deep sweeps of the knife so that no ragged edges are left as the muscles retract (4) The femoral vessels are doubly ligated, and all other visible bleeding points are secured The long saphenous vein requires a ligature of its own. (5) The sciatic nerve is pulled down a little from the wound surface and cut across so that it retracts and care taken that any accompanying vessels are secured before the nerve disappears otherwise there may be an annoying source of hæmorrhage from an inaccessible point (6) The tourniquet is removed and final hæmostasis secured muscle ooze being controlled by large deep bites of catgut (7) The deep fascia is sutured with interrupted catgut and the skin with interrupted silkworm gut or nylon A drain is not usually required (8) Dressing of tulle gras gauze and two layers of cotton wool are applied and a firm stump bandage is put on to hold the dressings in position and maintain pressure

Amputations through the Condyles of the Femur

In the *London and Edinburgh Journal of Medical Science*, Syme advocated a method of amputation through the condyle of the femur as especially suitable in cases of diseased knee joints. He said that amputation at this site had certain advantages —

(1) The shaft of the bone being untouched there is no injury to the medullary cavity and hence no fear of inflammation of its lining membrane.

(2) There is less risk of sequestration the cancellated texture of the epiphysis not being liable to sequestration.

(3) Being close to the joint the muscles are cut through at the tendinous part thus considerably diminishing the risk of retraction and consequent protrusion of bone.

(4) A large broad surface of bone is left to bear the weight of the body and one which like the ankle joint stump will round off and afford a comfortable pad over which the skin of the flap will play freely.

All these reasons are surgical reasons given by a past master in the art but some of them have now become obsolete. For even as the surgeon has improved his art and surgery been made easier and less dangerous by modern methods the limb fitting surgeon also has made great strides. The limb fitting surgeon states that the extra length is of no value from any point of view. End bearing cannot be tolerated for long even by transcondylar amputations without harm resulting to the stump, and circulatory disturbances occur sooner or later necessitating re amputation.

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It is revealing to study the reasons why Skey did not think this a suitable operation. He considered its use to be comparatively rare and, for it to succeed the following conditions were essential —

(1) There should be abundant skin in front of the knee-joint to make a long anterior flap.

(2) The patella and articular surface of the femur should be healthy.

These two conditions he says exclude nearly every case of disease or accident. If the joint is diseased and amputation is decided upon then obviously a thigh amputation should be undertaken. *If injured and the front of the knee is safe* he says it may very likely be possible to amputate below the knee.

Disarticulation at the Knee-joint

A disarticulation of the knee has certain well marked advantages —

(1) It provides a large horizontal end bearing surface for the lower extremity

(2) The skin, the soft tissues and the bone at the end of the stump have all previously been adapted to weight bearing by Nature

(3) Muscular control of the stump is achieved by preserving the origins and insertions of the muscles which control the stump

Fig 35 Amputation through the knee-joint (End bearing stump.) Patients walk well when fitted with artificial limbs for this type of stump.

(4) Good leverage can be exerted on a prosthesis because the stump is long and its end is firm and not tender

(5) The bulbous end of the stump enables a prosthesis to be fitted and controlled without suspension from the trunk. This ensures smooth and good walking

(6) The vascularity of the terminal tissues is good when the popliteal artery is ligatured below the origin of the superior geniculate branches leaving rich arterial anastomoses available at the end of the stump The greater part of the terminal flap which comes from the front of the joint, already has its own blood supply from the underlying tissues. Disarticulations at the knee are not so liable to circulatory defects as are long above-knee stumps

(7) In children 90 per cent of the growth of the femur takes place at the lower end The preservation of the lower femoral epiphysis allows normal development of the stump in childhood

(8) It should be done in elderly patients who will be better off with a disarticulation at the knee than with an above-knee amputation They will find the artificial limb easier to manage and have less difficulty in balancing because it is an end bearing stump

Technique of Disarticulation at the Knee-Joint

(1) In cutting the skin flaps a generous amount of skin should be allowed A semilunar incision, convex downwards, is made a hand s breadth below the level of the knee-joint

(2) Similarly a semilunar incision of equal perimeter is made behind meeting the former at both ends

(3) The skin should not be dissected from the subcutaneous tissues as the subcutaneous tissues should be kept as a single layer with the skin in order to preserve the minute blood vessels which nourish the skin The cuff of skin and fascia is dissected up until the ligamentum patellæ is reached

(4) The posterior flap is now dissected up to include skin and deep fascia

(5) The ligamentum patellæ is then divided at the level of the knee joint Thus the knee-joint is entered

(6) The knee is then flexed and the knife introduced between the femur and the semilunar cartilages

(7) The coronary ligaments are divided together with the synovial membrane

(8) The knee is next flexed to a right angle and the collateral and cruciate ligaments are divided

(9) The popliteal space is now entered and the muscles nerves and vessels in the space divided and ligatured as low down as possible The blood vessels should be carefully ligatured at the lower point

(10) The limb is then removed and the anterior flap turned upwards

FIG 36 Amputation below the knee The ideal stump measures 5½ in. and not 7 in. as taught formerly Note that the fibula is shorter than the tibia by 1 in.

FIG 37 Result of ideal below knee amputation.

(11) The patella is enucleated the pad of fatty tissue around is carefully preserved and closed with catgut sutures

The posterior projections of the two condyles necessitate a cumbersome artificial limb with a plug fit If a condylectomy is desired both femoral condyles can easily be removed with an osteotome so that the popliteal surface of the femur is flush with the posterior surface of the shaft of the femur Its rough edges should then be trimmed and this will still leave a useful end bearing stump The origins of the gastrocnemius muscle can also be removed. The tourniquet is then removed and all bleeding points are clamped and ligatured. The posterior tissues are approximated with a few catgut

sutures to the infrapatellar tissues This leaves a good pad of tissue over the end of the condyles allows the skin to be mobile and does not interfere with its nutrition The wound is carefully closed in layers care being taken that there should be no tension. The suture line is behind the condyles of the femur and the cicatrix will ultimately be drawn well upwards behind

At the end of the operation there should be a good pad of tissue over the lower ends

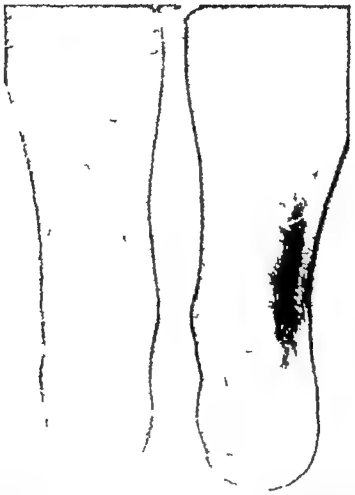

Fig 38 Bilateral below knee amputation for Buerger s disease. The right is of some years duration. The left is recent Notice (1) the length of the stumps which is shorter than usual, (2) the shape of the left stump which has not reached its permanent state and (3) the integrity of the skin in front of the tibia.

of the femur Drainage should be with a corrugated rubber drain as a hæmatoma is prone to form after these amputations

Amputations below the Knee

Before deciding on below knee amputation an X ray examination should always be carried out because it is unwise to preserve an arthritic knee in a below knee stump which may ultimately prove functionally unsatisfactory

The best length for a below knee stump for all purposes is from 5 to 6 in (12 to 15 cm) measured from the inner articular surface of the tibia to the end of this bone Stumps

longer than this in time develop circulatory troubles which may be aggravated by the type of fitting given

When we consider below knee stumps which are longer than the ideal we find the same circulatory defects so noticeable in over long above knee stumps and for these ischial bearing is more necessary than for shorter stumps in which the circulation is better Shorter stumps can be fitted and do very well in fact, the shorter the stump the better the circulation but it is wise to remember one may reach the point when the bone is too short to actuate a limb and be retained within the socket The shortest stump successfully fitted with a below-knee limb is 1¾ in (4 cm) but this is very exceptional It is important that there be no scars upon the anterior aspect of the stump The amputation, if performed by the lateral flap method *is most unsatisfactory* producing as it does an antero posterior scar at the extremity of the stump which becomes drawn up between the ends of the tibia and fibula In this position it is liable to traction and splitting with ulceration as a not infrequent result From the prosthetic aspect an anterior flap giving a posterior transverse scar would be the best but in a below knee amputation the circulation is

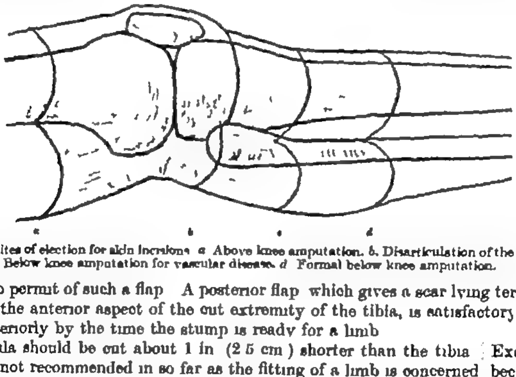

FIG 39 Sites of election for skin incisions *a* Above knee amputation. *b*. Disarticulation of the knee *c* Below knee amputation for vascular disease. *d* Formal below knee amputation.

insufficient to permit of such a flap A posterior flap which gives a scar lying terminally but towards the anterior aspect of the cut extremity of the tibia, is satisfactory since it retracts posteriorly by the time the stump is ready for a limb

The fibula should be cut about 1 in (2 5 cm) shorter than the tibia Excision of the fibula is not recommended in so far as the fitting of a limb is concerned because the presence of the fibular head serves a useful purpose in providing a prominence around which the socket is fitted thus preventing a tendency for the limb as a whole to rotate

Usually it is found possible to fit a below knee stump about two months after amputation, but the conditions relating to above-knee stumps apply also to below knee amputations In cases of previous sepsis fitting will be found impossible until a later date and when there is no sepsis post-operative anæsthesia is occasionally found, which delays fitting

Technique of Amputation Below the Knee

(1) A tourniquet is applied in the upper thigh It is an advantage to have a wedge block under the calf (2) Equal antero posterior flaps are cut to give a stump 5½ in

(15 cm.) in length when measured from the joint line The original incisions should include deep fascia the periosteum of the tibia being utilized where the bone is subcutaneous and the flaps are dissected up a little way deep to the fascia It is important not to undercut this any more than is necessary in order to expose the level of the bone

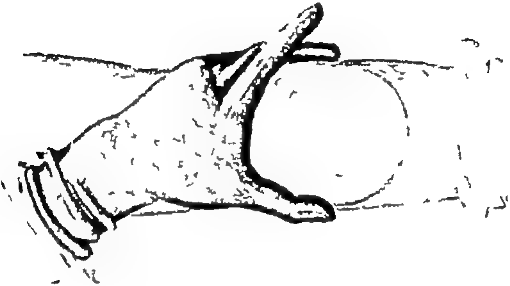

Fig 40. The outline of a skin incision showing the length and contour which is most suitable.

division and the full thickness of the flap should be preserved undisturbed as an anatomical dissection of layers merely results in bruising œdema subcutaneous blisters, and hæmatoma formation

(3) The soft tissues are then divided at the level of the bone section and the fibula

Fig 41 Below-knee amputation. Skin incisions and fascial incisions. Note that the fascial incision is slightly distal to the skin incision.

is cleared of muscle for an inch higher than this point There is a tendency after dividing the muscles for the tibialis anterior and the muscle mass which is adjacent to the tibia to separate from the bone which separation is further increased by rough periosteal stripping This should be avoided as it leaves a potential space increases bleeding and robs the bone of some of its blood supply

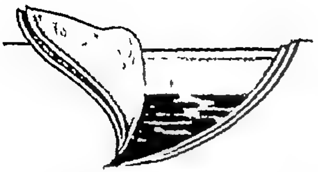

FIG 42. The skin and fascia together with the periosteum have been dissected off exposing the tibia and the muscle

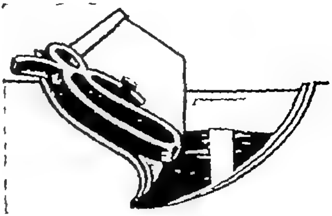

FIG 43 Saw in position prior to section of the bone in a below knee amputation. Notice starting point and angle of inclination The muscles have already been sectioned.

(4) The tibia is first bevelled and then sawn across at the selected site Bevelling should begin at least ½ in (1 5 cm) proximal to and should continue until it has reached the level of the cut end of the muscles The saw should be directed downwards at an angle of 30° to the bone surface When it has reached the level of the cut end of the muscle the tibia is about half sawn through (5) The blade is then removed and the final dividing cut made at right angles to the bone surface meeting the oblique cut to form the anterior bevel and severing the tibia

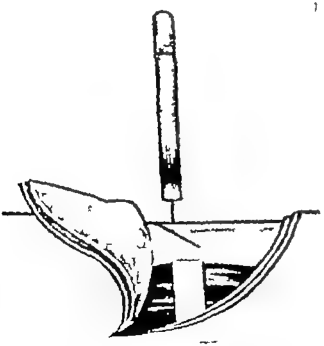

FIG 44 Saw in position prior to complete section of the tibia. The line of the final saw cut and the muscle will correspond.

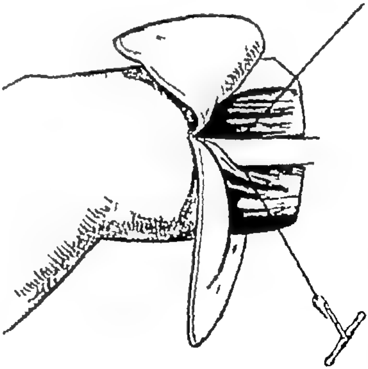

FIG 45 Lateral view showing the tibia adequately bevelled and the fibula being shortened with a Gigli saw (For clarity the Gigli saw is here represented in the reverse direction from that which is used in practice.)

(15 cm) in length when measured from the joint line The original incisions should include deep fascia the periosteum of the tibia being utilized where the bone is subcutaneous and the flaps are dissected up a little way deep to the fascia It is important not to undercut this any more than is necessary in order to expose the level of the bone

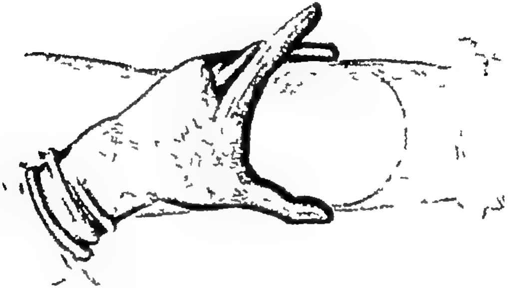

Fig 40 The outline of a skin incision showing the length and contour which is most suitable

division and the full thickness of the flap should be preserved undisturbed as an anatomical dissection of layers merely results in bruising œdema, subcutaneous blisters, and hæmatoma formation.

(3) The soft tissues are then divided at the level of the bone section and the fibula

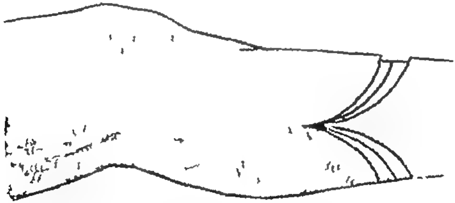

Fig 41 Below knee amputation. Skin incisions and fascial incisions. Note that the fascial incision is slightly distal to the skin incision.

is cleared of muscle for an inch higher than this point There is a tendency after dividing the muscles for the tibialis anterior and the muscle mass which is adjacent to the tibia to separate from the bone which separation is further increased by rough periosteal stripping This should be avoided as it leaves a potential space increases bleeding and robs the bone of some of its blood supply

Fig 49 Below-knee amputation. Fibula has been shortened and lower end of tibia bevelled. (Satisfactory amputation.)

Fig 50 Below knee amputation. This is not a satisfactory result The stump is too long No attempt has been made to bevel the lower end of the tibia or shorten the fibula. Spur formation from lower end of both bones and soft tissue calcification below the end of the fibula with fragments of loose bone infection and sinus formation.

(10) The deep fascia is sutured with interrupted catgut and the skin with interrupted silkworm gut A drain is not normally required Dressing is the same as for the above knee but a back splint should be bandaged to the thigh and stump over the dressing and left on for forty-eight hours to prevent flexion.

(6) The fibula is next divided at a level 1 in. (2 5 cm) higher than the tibia, in adults and even higher in children if possible

Division of the fibula by the *Gigli saw* is a method which is superior to division by bone forceps as it does not splinter the bone (see Fig 45) This should be done from the medial to the lateral side It produces a clean oblique cut of the fibula and is in conformity with the desirable convex shape of the stump

(7) The ends of the tibia are rounded off with a file

(8) Anterior and posterior tibial vessels are ligated and the nerves gently pulled down and divided an inch from the end of the stump

(9) The tourniquet is removed and final hæmostasis secured by deep catgut sutures through the muscles.

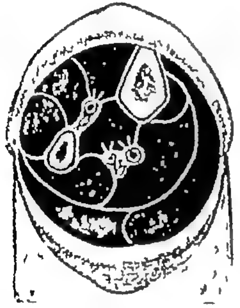

Fig 46. End-on view showing the disposition of the muscles and the vessels which have been ligatured.

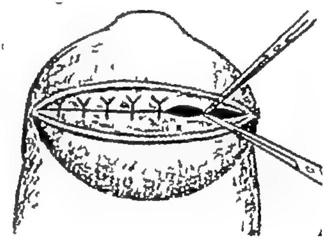

Fig 47 End view showing the fascia which is being sutured. The skin line will fall over this area.

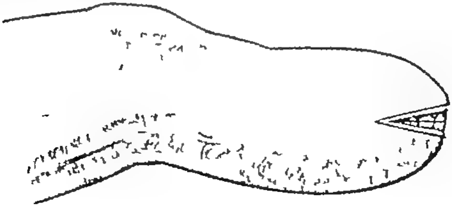

Fig 48. The fascia layer has been sutured and the skin is awaiting suture. Notice that the line of suture will be on the end of the stump.

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(8) Two artery forceps are placed on the subclavian vessels and ligatures are applied by means of an aneurysm needle on each side of the forceps The ligatures are secured and left long

(9) The subclavian artery and vein are then divided between the artery forceps The cords of the brachial plexus are cut with scissors close to the spine There is no advantage in injecting a local anæsthetic for these nerves before division

(10) The operation is now continued by making the anterior pectoro axillary flap by reflecting the skin as far forward as is necessary

(11) The operation is completed by dividing the pectoralis major and minor muscles

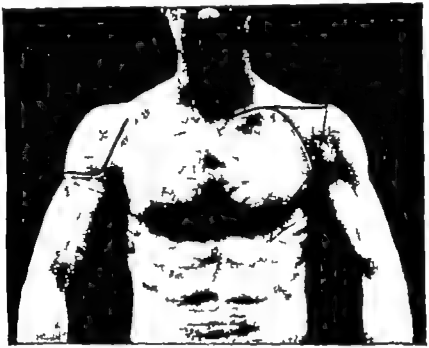

Fig 51 Right side shows the incision over a subcapital amputation and the left side shows the incision for a forequarter amputation.

(*Operative Surgery* Miles and Wilkie Oxford University Press

(Usually these muscles need only be divided at their insertions unless that part of the humerus or scapula is involved in the amputation)

The fore-quarter will now come away easily from the thoracic wall (The thoracic boundary of the axilla with the contents of lymphatic glands can *then* be removed if they are diseased.)

(12) The flaps are next closed in layers and the skin with interrupted sutures Tension sutures will usually be found necessary A firm dressing is applied

This operation leaves the unfortunate patient with a very ugly sloping upper part of the chest wall A pad will be required suspended from the neck to give the appearance of a shoulder from which a coat can hang

Later on scoliosis results from the unbalanced weight but this can be counteracted to some extent by post-operative physiotherapy such as postural exercises

2 **Disarticulation at the Shoulder** (1) The arm is abducted and rotated well outwards (2) An incision is made beginning immediately external to the coracoid process and carried through the clavicular fibres of the deltoid as far as the lower border of the

CHAPTER IV

SPECIAL AMPUTATIONS

In the same manner that the blind man worketh in hewing of a log, so doth a surgeon that knoweth not anatomy

GUY DE CHAULIAC.

Upper Extremity

1 **Fore-Quarter (Interscapulo-Thoracic) Amputation.** Ralph Cuming an English surgeon performed the first recorded interscapulo thoracic amputation in 1808 In 1882 Paul Berger Professor of Surgery in Paris amputated the whole upper limb in a patient with an enchondroma of the humerus

This mutilating operation is rarely performed Among the few indications are malignant growths, or the presence of a large chondroma of the scapula or the upper end of the humerus The whole upper limb the outer end of the clavicle and the entire scapula are removed in one piece

PRELIMINARY A blood transfusion is started after the patient has been anæsthetized, and before the operation is begun The patient is placed on his sound side close to the edge of the operating table Littlewood s technique is the simplest and most expeditious method of performing this operation. The type of incision will vary according to the site of the tumour As a rule two incisions are planned—a cervico-scapula and a pectoro-axillary

DESCRIPTION OF THE OPERATION

(1) The cervico-scapular flap is made by starting near the outer border of the sterno mastoid attachment to the clavicle and carrying the incision along the clavicle over the prominence of the shoulder along the posterior axillary fold to a point between the angle of the scapula and backwards to about 2 in (5 cm) from the spine

(2) This large flap of skin and subcutaneous tissue is turned back exposing the posterior surface of the scapula together with the muscles which attach it to the spine

(3) The trapezius and the latissimus dorsi muscles are divided, together with the levator anguli scapulæ and rhomboid muscles

(4) Next the scapular attachment of the serratus anterior and omohyoid muscles is severed (At this stage several large vessels will require ligature i e branches of the supra-scapular and posterior scapular arteries)

(5) The clavicular attachment of the sternomastoid muscle is separated with a knife

(6) This is followed by sub periosteal dissection of the clavicle with an elevator

(7) A Gigli saw is then passed under the clavicle and the bone is divided just lateral to the sterno-clavicular joint exposing the subclavius muscle whose severance will enable the whole upper extremity to fall away from the trunk. This last manœuvre places the subclavian vessels and the cords of the brachial plexus on the stretch and they can now be easily seen

caught up and ligatured No attempt is made to inject any of the nerves which have all been cut short The wound is carefully closed in layers with a drain at the lower end

Lower Extremity

Hind-quarter Amputation When Harvey discovered the circulation of the blood, at the beginning of the seventeenth century, more rational methods for the control of hæmorrhage in operations began to be adopted Amputations which had long been practised gradually commenced to be a more controlled procedure, and much of the anxiety of hæmorrhage was removed Apart from the morbid conditions which demanded amputation hæmorrhage shock and sepsis made amputation a dangerous procedure To-day this is not so apart from such ætiological factors as age general health or concomitant disease There is only one operation which gives rise to anxiety the inter innomino-abdominal operation It was not until 1895 that a successful result was obtained by Girard Since that time the operation has been performed by many surgeons with increasing success due to improved methods of resuscitation and control of hæmorrhage together with increasing technical operative experience

FIG 53. A typical case requiring hind-quarter amputation. This man had an infiltrating chondro-sarcoma of the ilium, extending so far back that sacro-iliac disarticulation was necessary The scar of an attempted previous local excision is visible.

[*L. P Le Quesne Postgraduate Medical Journal.*

Sir Gordon Gordon Taylor in 1946 reported a series of twenty-one personal cases, and since that time has performed a further forty-eight such operations It is largely as a result of his work that this formidable ablation has been established in this country, as a standard procedure in the surgical management of malignant disease affecting the root of the limb where disarticulation of the hip joint would be inadequate

pectoralis major This incision goes down to the bone (3) The cephalic vein and branches of the acromio thoracic and anterior circumflex arteries are divided and ligatured (4) The anterior fibres of the deltoid, pectoralis major and the long head of the biceps are then divided (5) The incision is carried round the outer aspect of the arm through the lower fibres of the deltoid towards the posterior axillary fold. This portion of the incision is also made down to bone (6) Beginning at the lower end of the original vertical incision the skin and fascia on the inner aspect of the arm are divided until they meet the outer incision (7) The inner incision is then carefully deepened, and the main

Fig 52. Fore-quarter amputation for a chondro-sarcoma of the scapula. Resultant scar after stitches have been removed.

vessels dissected out secured ligatured and divided. (8) The deltoid muscle is dissected up by keeping the knife close to the bone so as to avoid the posterior circumflex artery (9) The arm is rotated outwards and the capsule is divided together with the subscapularis muscle (10) The arm is now rotated inwards and the muscles attached to the greater tuberosity namely the supraspinatus infraspinatus and teres minor are separated (11) Next the knife is passed behind the bone to separate the long head of the triceps and then down on the inner side to divide the muscles in the bicipital groove—the biceps coraco-brachialis latissimus dorsi and teres major (12) After removal of the arm a large pack is inserted into the cavity All the small bleeding points are carefully

On occasion the operation has been performed for extensive tuberculous or chronic inflammatory disease of the hip joint and pelvic bones

Position on the Table—Preliminary The patient is placed lying on his sound side with a sandbag in the small of the back and another under the thigh on the sound side The upper arm is fixed on an arm rest while the lower is held on a board The surgeon stands behind the patient He should have three assistants One holds the leg to be amputated the second stands beside the surgeon, and the third by the side of the second

Blood transfusion is started in the form of two intravenous drips This is important as the patient may need a rapid massive transfusion One transfusion can be started in

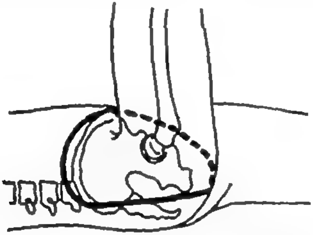

FIG 57 Diagram illustrating the incision used for hind-quarter amputation. In certain cases modifications may be required to secure adequate flaps.
[*L. P Le Quesne Postgraduate Medical Journal.*

the forearm of the unaffected side and the other on the back of the forearm on the affected side

A gum elastic catheter is introduced and tied into the urethra before the operation is commenced

In the case of a malignant growth the leg should not be exsanguinated before the operation A piece of oiled silk is stitched over the anus to isolate this so that it cannot contaminate the operative field.

The Operation First Stage

The incision employed is that designed by Girard (1) It begins at the symphysis pubis and extends across the iliac fossa to the anterior superior spine of the ilium It continues downwards over the greater trochanter and across the gluteal fold then upwards to its point of origin. (2) The attachment of the rectus abdominis muscle is cut and the inguinal ligament is divided at its attachments to the pubis and the anterior iliac spine

If any doubt exists as to the extent and fixation of the disease in the case of a neoplasm for instance on the inner aspect of the innominate bone both extent and fixation can readily be ascertained at this stage of the operation (3) The inferior epigastric vessels are ligated and divided and the spermatic cord is retracted (4) At this stage the iliac fossa and the retroperitoneal pelvic space are exposed by retracting the detached abdominal wall and peritoneum medially

FIG 54. A very large osteochondroma which later became sarcomatous, necessitating hind-quarter amputation.

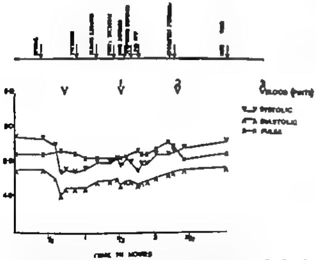

FIG 55 Showing the serious degree of shock associated with sacro-iliac disarticulation. Note the improvement consequent upon rapid massive transfusion. (Figs. 55 and 56 are reproduced by kind permission of Dr Brian Sellick, who gave the anæsthetic in these two cases.)

[*L. P. Le Quesne. Reprinted from the Postgraduate Medical Journal.*

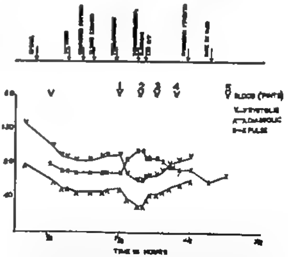

FIG 56. Graph showing blood pressure and pulse during an uncomplicated hind-quarter amputation. Compare with Fig 55

[*L. P. Le Quesne. Reprinted from the Postgraduate Medical Journal.*

On occasion the operation has been performed for extensive tuberculous or chronic inflammatory disease of the hip joint and pelvic bones

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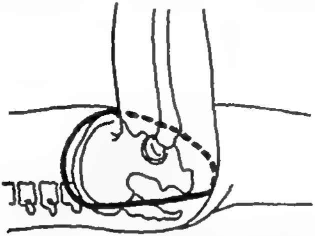

FIG 57 Diagram illustrating the incision used for hind-quarter amputation In certain cases modifications may be required to secure adequate flaps.
[L. P Le Quesne Postgraduate Medical Journal.

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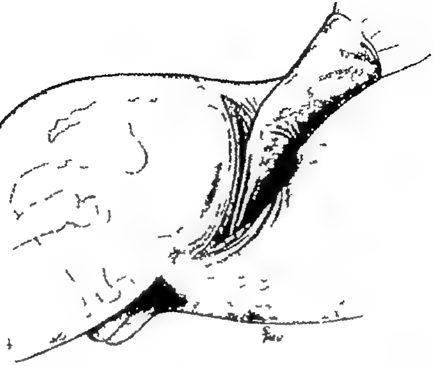

Fig 58 The incision parallel to the iliac crest has been deepened through the muscles, and a hand is inserted to explore the inward, pelvic extent of the tumour

[L. P. Le Quesne Postgraduate Medical Journal.

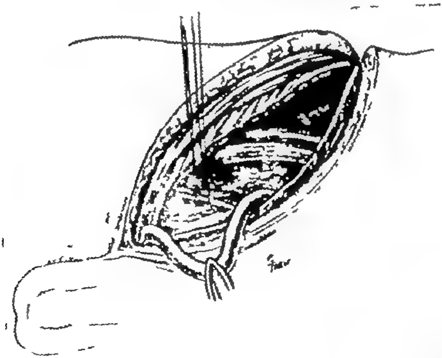

Fig. 59 The ligation of the inferior epigastric vessels. The spermatic cord has been mobilized and retracted well medially

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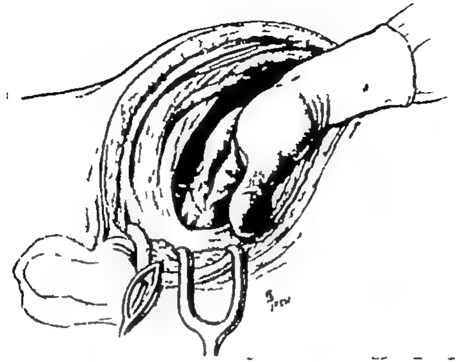

FIG 60. With a hand inserted to retract and shield the bladder and peritoneum, the rectus muscle is detached from the pubis.

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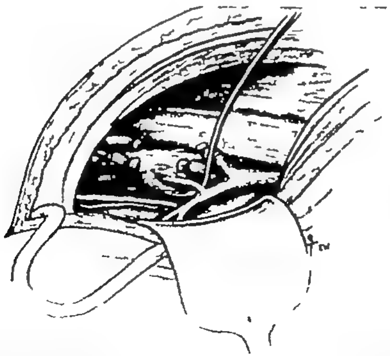

FIG 61 Ligation of the posterior division of the internal iliac artery The external iliac vessels have already been divided between ligatures. The obturator nerve can be seen lying just below the apex of the sacro-sciatic notch which has been dotted in to demonstrate its position in relation to the vessels.

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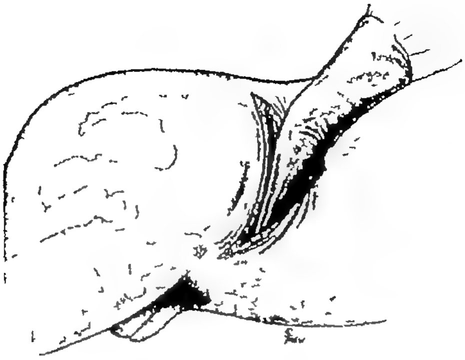

FIG. 58. The incision parallel to the iliac crest has been deepened through the muscles, and a hand is inserted to explore the inward, pelvic extent of the tumour

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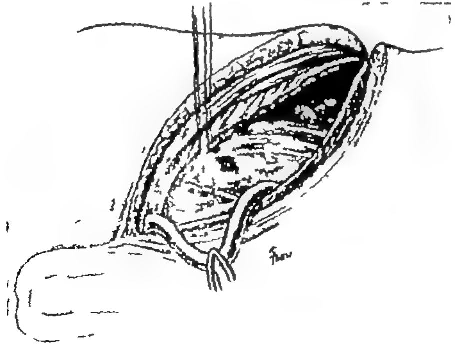

FIG. 59. The ligation of the inferior epigastric vessels. The spermatic cord has been mobilized and retracted well medially

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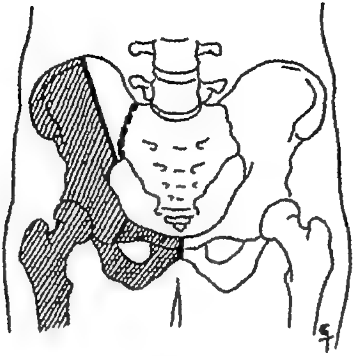

FIG 63. Diagram to show the lines of bone section The shaded area shows the amount of bone normally excised, though on occasion sacro-iliac disarticulation may be required as shown by the dotted line

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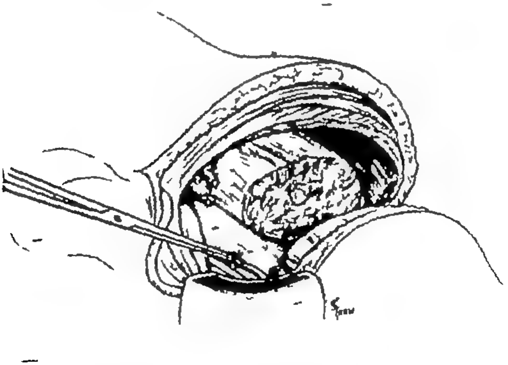

FIG 64. The anterior dissection has been completed by section of the psoas and iliacus muscles, between which two structures can be seen the divided femoral nerve. Forceps have been inserted into the sacro-sciatic notch, at the site of bone section

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(6) The gluteal and obturator vessels and nerves the sciatic nerve and the pyriformis and levator ani muscles are sectioned (7) The sacro tuberous sacro-spinous and posterior sacro iliac ligaments are then further severed (8) Returning to the anterior dissection,

In the case of a growth the tumour mass will be seen to fill the iliac fossa and its whole extent can be investigated as far back as the sacro-iliac joint

The ureter should be carefully avoided it is generally adherent to the peritoneum and is reflected with it

(5) It is important to expose the common iliac external iliac and hypogastric arteries A controlling tape is then placed round the common iliac artery which is occluded throughout the remainder of the operation.

(6) The external iliac artery is doubly ligated and divided. The symphysis pubis is well defined and divided with a chisel The amount of bleeding at this stage is usually minimal.

Second Stage

(1) The patient is then gently turned further over on his sound side and the posterior dissection is begun by cutting through the muscles attached to the iliac crest and the

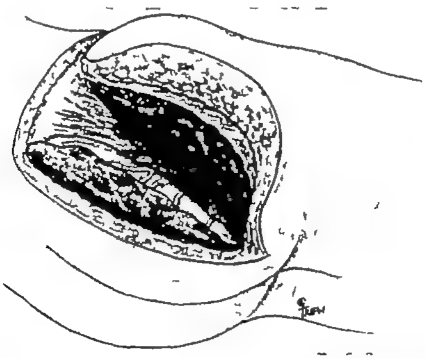


FIG 62. The posterior incision has been deepened through the gluteus maximus, to expose the posterior aspect of the sacro-sciatic notch. The dotted line indicates the line of division of the ilium.

[L. P. Le Quesne, *Postgraduate Medical Journal*

gluteal attachments to the posterior surface of the sacrum The dorsum of the ilium and the sciatic notch are exposed. (2) At this stage a Gigli saw is introduced underneath the sciatic notch and led through the notch from within the pelvis (3) The Gigli saw is then withdrawn by means of a strong pair of forceps on to the dorsum of the iliac bone

(4) It is more expeditious and produces less shock to saw through at the site of the sciatic notch than to disarticulate at the sacro-iliac joint but if the extent of the tumour growth does not permit splitting the ilium at the sciatic notch, the much more difficult procedure of disarticulation at the sacro-iliac joint has to be undertaken (5) After the ligaments have been cut an osteotome is introduced into the sacro iliac joint and the two surfaces are separated

pubo rectalis muscle which is inserted behind the pubes (10) All small bleeding points are then caught up and the controlling tape in the common iliac artery is removed Normal pulsation occurs in this artery in the hypogastric, and in the stump of the external iliac artery The amount of hæmorrhage is again minimal This method of temporary occlusion of the common iliac artery provides excellent vascular control of the whole area and makes the operation a much safer procedure (11) The skin flaps are approximated after the peritoneum has been reinforced by suturing the remains of the gluteus maximus and levator ani muscles to the flank muscles and the rectus abdominis Through and through interrupted silkworm sutures are used

The most important points in successfully conducting this operation are the following —

(1) Spinal anæsthesia eliminates some of the shock in this drastic operation which involves severing of the lumbo-sacral cord and of the first and second sacral and the obturator nerves

(2) Adequate blood transfusion should be started at the beginning of the operation and carried on until the operation has been successfully completed and the blood pressure of the patient has again become stationary

(3) Hæmorrhage is made minimal by temporary occlusion of the common iliac artery which provides excellent vascular control

(4) Sawing through the dorsum ilii at the level of the sacro-iliac notch is a simple and expeditious method of dividing the bone, and eliminates the shock and trauma of disarticulation of the bone at the sacro iliac joint

(5) *Gentle handling* of the patient and of the tissues further lessens shock

(6) The danger of necrosis of the posterior skin flap incidental to common iliac artery ligation is avoided

Post-operative Care

(1) The patient is returned to a warm bed, with the foot of the bed raised. The drip is usually required until the next day and as much as ten pints of blood may be needed

(2) It is necessary to keep the catheter *in situ* in the bladder for three or four days after operation and to have it connected to a tidal drainage apparatus

(3) The first dressing in the ward when the drainage tubes are removed should be done under light pentothal anæsthesia The stitches should be left in as in all amputation cases for ten to fourteen days

(4) The patient should be given the freedom of the bed and encouraged to move about This will not only help to ventilate his lungs and prevent post-operative thrombosis but will also assist the nursing staff when they attend to his pressure points He can of course be rolled on to either side for attention to his back

(5) Blood counts are necessary to investigate the hæmoglobin level, for several weeks after the operation

(6) After the wound has healed the patient should be encouraged to become ambulatory on crutches When the operative sites are soundly healed and not tender a temporary pylon over an abdominal corset which fits the amputation area can be made for him

(7) In six months time he can be fitted with an artificial leg

In spite of the severity of this ablation these patients are able to walk and to lead

the psoas muscle and femoral nerve are divided, while the external iliac vein is isolated and doubly ligated before it too is divided.

(9) It will now be seen that the extremity is almost free for removal and can be drawn away from the intact pelvic peritoneum by division of the anterior portion of the

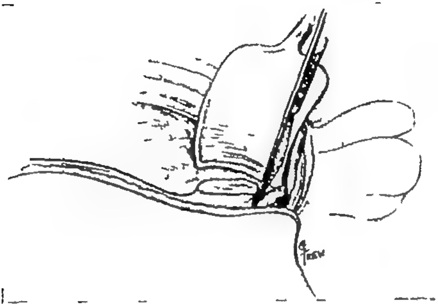


FIG 65 A diagram to show the crus penis being cut off the pubic ramus, after both bone sections have been made and the half pelvis retracted laterally and backwards.
[L. P Le Quesne, *Postgraduate Medical Journal*.

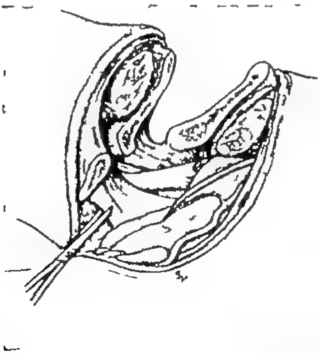


FIG 66 The levator ani is divided from before backwards, its anterior pubo-rectalis portion being thick and muscular During this procedure the rectum, bladder prostate and peritoneum must be protected from injury The sciatic nerve can be clearly seen running across the face of the piriformis muscle the ureter vas and cord are also shown in contact with the peritoneum.
[L. P Le Quesne *Postgraduate Medical Journal*.

a normal life Compensatory scoliosis should be watched for and can be guarded against by planned exercises to improve the tone of the erector spinæ and abdominal muscles

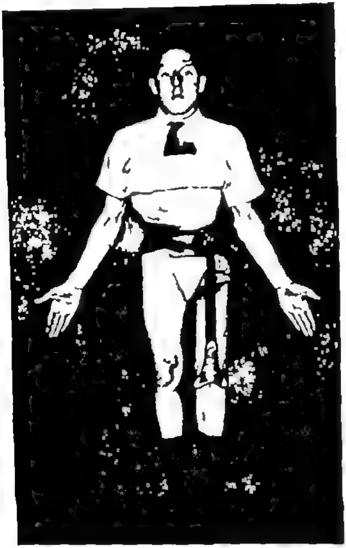


FIG 68 V P two and a half years after left hindquarter amputation; he is wearing the special prosthesis. (This photograph is reproduced by kind permission of the Director of Medical Services, Roehampton Hospital and Mr Ivor Lewis, F R.C.S.)

[L. P Le Quesne Postgraduate Medical Journal.

Disarticulation at the Hip

Disarticulation of the hip is not a common operation and is usually performed for malignant disease

The most suitable flaps except where surgically contra indicated are unequal antero posterior ones the posterior flap being about four times longer than the anterior It will be found when the final suturing is done that the suture line falls in front and that the perimeters of the two flaps are almost identical

(1) The best incision is a semi lunar one which starts at the pubic spine and curves downwards towards the mid point of the inguinal ligament (vertically to about 3 in (7 5 cm) in the adult and 1½ in (3–4 cm.) in a child of ten) then upwards to a point just

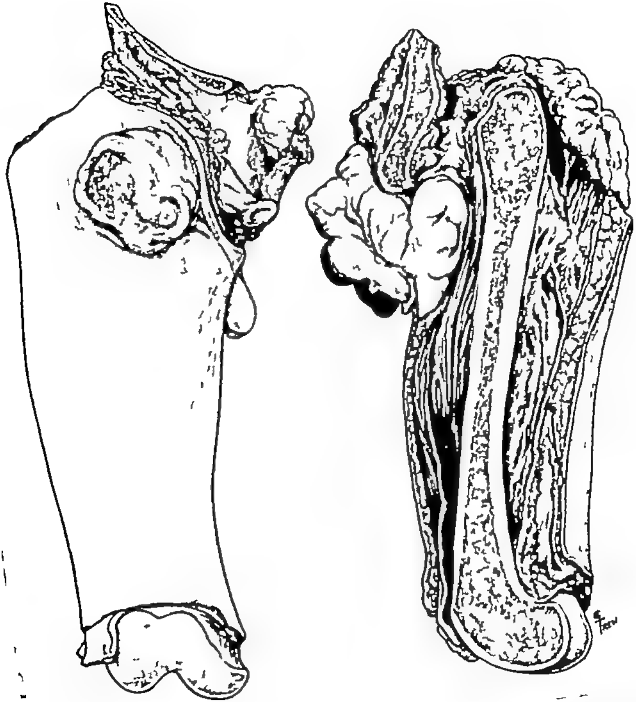


FIG 67 Two views of a specimen removed by hindquarter amputation This man had a reticulum-cell sarcoma of the inguinal lymph glands, which had recurred after heavy irradiation. The tumour was infiltrating the ilium and ulcerating through the skin.

[L. P. Le Quesne *Postgraduate Medical Journal.*

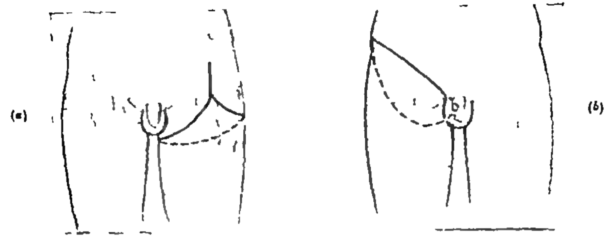
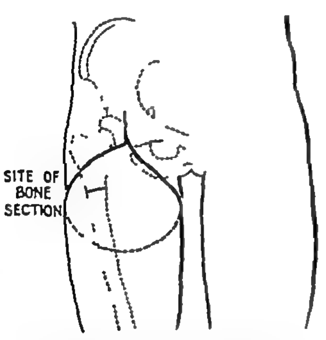


FIG 72. (a) Racket incision for hip amputation and (b) Fitzmaurice-Kelly incision for disarticulation of hip.

lateral to the anterior superior iliac spine Alternative incisions could be made as follows —

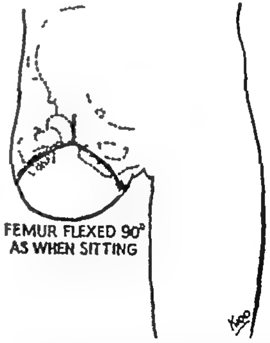
(a) A vertical incision 3 in long (7 5 cm) is made from the inguinal ligament along the line of the femoral artery (b) The incision is carried obliquely down the inner side of the thigh to a point 4 or 5 in (10–12 cm) below the genito femoral fold It then extends across the back of the limb and up over the outer aspect to meet the handle of the racket in the inguinal fold The incision is made a little lower on the inner than on the outer side (2) The anterior flap is dissected upwards towards the inguinal ligament (3) The femoral vessels are dissected out first the artery and then the vein and doubly ligated



INCISION FOR ANTERIOR SCAR

FIG. 73. Incision for a subtrochanteric amputation of the femur This will result in an anterior scar

[A. J Craft Ann. Roy Coll. Surg Eng.



RESULTANT ANTERIOR SCAR

FIG 74 High above-knee amputation. A racket incision has been used and the resultant anterior scar line is shown.

[A. J Craft, Ann. Roy. Coll. Surg Eng.

FIG 69 (a) Disarticulation at the hip-joint Note the lack of prominence of the lateral contour which eliminates the ledge for the fitting of a tilting table. This is of cosmetic importance in women.

FIG 69 (b) Lateral view of a disarticulation of the hip. Note the regular contour of the stump which results with this operation.

FIG 70. Pertrochanteric amputation. Showing the prominence of the lateral contour Upon this an artificial limb socket can be moulded.

FIG 71 (a) Subtrochanteric amputation. Posterior view of left pelvis with stump dependant The relative horizontal levels of the ischial tuberosity and the stump extremity require the fitting of a tilting table type of limb which is worn when the femoral stump becomes flexed at an angle of 90°

FIG 71 (b) Lateral view of a subtrochanteric amputation the ilio-psoas muscle flexes the stump and gives rise to an anterior prominence.

[*By courtesy of J. E. Hanger and Co., Ltd.*

FIG 75. Modified Syme's amputation The section here has been made too high. This is not usually considered a satisfactory level for amputation owing to liability of circulatory disturbance and formation of painful small bony spurs.

FIG 76. Long-standing Syme's amputation (35 years) There is some irregular new bone formation from the under-surface of both tibia and fibula.

and divided respectively (4) The femoral nerve is divided (5) The anterior femoral muscles are then divided preliminary to opening up the joint (6) The four adductor muscles the sartorius tensor fasciæ femoris and the anterior femoral muscles are divided. (7) The deep femoral, the external and internal circumflex arteries and their branches are now caught up and divided (During this part of the procedure any inguinal glands which are encountered should be dissected out and removed. The posterior incision is a convex flap which starts at the medial end of the first incision and passes downwards convex inferiorly for about 6 in (15 cm) in the adult and 4 in. (10 cm) in the child to meet the first incision lateral to the anterior superior iliac spine) (8) The flap is then dissected up towards the buttock superficial to the deep fascia (9) The hamstring muscles the glutei quadratus femoris and ilio psoas muscles are divided (10) The following vessels are caught up and divided the superior and inferior gluteal *arteries the first perforating branch of the profunda femoris and the internal saphenous* vein (11) The sciatic nerve is divided as well as the obturator and the external and posterior cutaneous nerves of the thigh. (12) The capsular and teres ligaments are divided thus allowing the lower extremity to be removed (13) After removing the lower extremity the large cavity is packed with a towel and all bleeding points are carefully caught up and ligatured The wound is drained and closed in layers

Syme's Amputation

A painful foot may be caused by some trivial injury or ailment A defect in a toe may sometimes produce total incapacity for duty A correct diagnosis followed by simple treatment will often result in an early return to active work. With patience and judgment it is remarkable what good results follow conservative treatment of the feet Major surgery including amputation is indicated only for serious wounds and foot deformities Amputations should be resorted to only when the foot is mutilated and mangled beyond hope and even then with the modern antibiotics and sulphonamide drugs amputation should be delayed Amputation is an easy escape from a difficult problem for everyone except the patient often courage and a second opinion, or even a third should be sought to resist amputation. It is natural that if the patient has been under the care of one surgeon for some time he and the surgeon have travelled the same road and discussed the same difficulties over a long time Hence both their judgments may sometimes be clouded A second opinion will often give a welcome refresher and new hope to both patient and surgeon

In the foot apart from the trans metatarsal amputation only one amputation can seriously be considered in the case of injuries Provided the tissues about the heel are intact and viable Syme's amputation still remains a good amputation. For almost one hundred years the operation has stood the test and has found favour in surgical literature Both the Edinburgh and Toronto schools believe Syme's to be an excellent amputation In England there is a difference of opinion as to its merits.

Elmslie surgeon at Roehampton in 1919 wrote Syme's amputation is the best amputation for the lower limb Some limb makers object to it but this is because it is more difficult to fit a prosthesis than in a straightforward amputation through the middle of the leg

A patient said Elmslie with a good Syme's amputation can walk ten to fifteen

in which case it is unwise to perform a Syme s amputation Syme s original description as quoted by Erichsen does not correspond in detail with Sir D Arcy Power s quotations from Syme s work Both descriptions may be summed up as follows —

The foot projects well over the end of the table The surgeon s left hand grasps the ankle His thumb and forefinger mark the tips of the malleoli (1) The point of the knife is entered just below the external malleolus Taking a direction slightly backwards

Fig 77 Arteriogram of amputation stump of patient aged 75 This shows that the peripheral vessels of the foot are still patent and the smaller network of vessels in the heel are well outlined. To obtain adequate vascularity of the heel flap in a Syme s amputation one should amputate below the division of the calcaneal arteries. Only in this way can the viability of the stump be assured.

the incision crosses the sole to a point ½ in (1 25 cm) below and behind the tip of the internal malleolus

It is better at this stage not to divide the tissues behind the malleolus lest the posterior tibial artery be severed before giving off its terminal branches Erichsen, however, states that this precaution is quite unnecessary (see below) The inclination of the incision should be decidedly backwards The common fault is to make too large a heel flap

(2) The heel flap is dissected off the plantar fascia and os calcis keeping the edge of the knife in close contact with the bone (3) The tendo Achillis is divided or raised with the periosteum (4) With the foot in plantar flexion the dorsal incision is now made It joins the two ends of the incision for the heel flap The dorsal incision passes across the

miles in an elephant boot and with a good artificial foot is able to run, jump and play such games as tennis and golf almost on equality with a whole man.

I disagree with the view that a below knee amputation is no worse than a Syme's and that the below knee amputee can do everything with an artificial limb that a Syme's can do. It has been stated by some fitters that although the Syme's has no advantages it has several disadvantages. The prosthesis they say will always be larger than that of the normal ankle and cosmetically it never looks natural but always has an artificial appearance particularly in women. Then again, the Syme's amputation is a difficult operation to perform and, unless it heals by first intention, it is extremely difficult to fit a prosthesis, whereas it is almost always possible to fit the average below knee amputee with a difficult stump comfortably even when the stump is scarred and has healed after sepsis. It should always be remembered however by those who reject the Syme's amputation and suggest a below knee amputation of 6 in (15 cm) that for a patient a below knee amputation is a big price to pay for a severe injury to the forefoot. The artificial limb in a Syme's amputation, grasps the leg from below the knee to the ankle so achieving intimate contact. Even without it the patient is able to dress and bathe. He can get up at night if necessary without an artificial aid.

In some cases the boot and fittings are so comfortable that they are worn from choice without intermission, throughout the day. On the other hand, however ceaseless activity with a Syme's stump causes heavy wear on the boot and side steels which consequently need frequent renewal.

Those who condemn the Syme's operation seem to have based their objections on the plight of a group of pensioners who appeared with Syme's stumps a number of years after the First World War. It is stated that there was ulceration, pain and poor vascularity. The circulatory deficiency resulted in re-amputation. But it should be stressed that some of these stumps were unsatisfactory because the operation had been performed, in the forward hospitals in France by people who were unaccustomed to performing this difficult operation. Furthermore in some cases the operation was contra indicated the original injury having involved the tissues of the heel. There can be no doubt that from the patient's point of view every inch of the limb that can be saved should be saved. Who has not seen the look of despair on the face of a patient and realized his sense of disaster when he is recommended to have a below knee amputation for a foot ailment? It should never be forgotten that something may happen to a patient's other leg. Like the good ophthalmologist the good orthopaedic surgeon should always bear in mind the possibility that the opposite organ may be damaged at some future date.

Syme's Operation

Disarticulation of the Foot at the Ankle Joint. The best descriptions of this hundred year-old procedure are given by the older writers. Syme introduced his operation with this statement: "It may be startling but it is nevertheless true that amputation at the ankle joint with hardly any exceptions, may and ought to supersede amputations below the knee." This statement may not be as true now as it was a century ago but we should still stop and think before resorting to a below knee amputation. Syme operated without a tourniquet. "An assistant," he said, "has complete command of the vessels by grasping the ankle." This is open to question. I recommend a tourniquet unless the vessels in the limb are diseased and are likely to suffer from the trauma of the tourniquet.

of the amount of bone to be removed (2) It is essential that the resultant cicatrix should not be on the plantar aspect (3) The effect of muscles acting in opposition must be allowed for so that there may not be a resultant tendency to deformity in any direction

In amputation through the ankle the operation of choice is that described by Syme, which consists of disarticulation at the ankle joint together with removal of the malleoli and the articular surface of the tibia The technique of this most successful operation has already been considered It is of historical interest to consider those which preceded

Fig 79 Bilateral Syme s amputation showing scar line and shaping in the immediate post-operative period. The heel flap has remained in position.

it Moreover in cases of trauma it is occasionally necessary as well as desirable to adopt one of the following procedures —

(1) SUBASTRAGALOID AMPUTATION This operation is occasionally *possible* in cases of injury where the astragalus remains undamaged This is not an ideal operation as the resultant stump is too long to enable a good *prosthesis* to be fitted

(2) TARSO-METATARSAL SITES Amputation is performed either by Lisfranc s or Hey s operation The former consists essentially of a *disarticulation* since no bone is sawn across (1) A slightly convex dorsal incision extending down to the bones is made from the base of the first metatarsal on the inner side to the projecting styloid of the

line of articulation i e about ½ in (1 25 cm) above the tip of the internal malleolus The ankle joint is opened while the foot is strongly plantar flexed (5) The lateral ligaments are divided by working the knife downwards on each side between the malleoli and the astragalus (6) The foot is then removed

If the lower ends of the tibia and fibula have escaped injury or disease only the projecting points of the malleoli are removed with saw or bone forceps The saw line must be kept strictly at right angles to the long axis of the leg when removal of the articular surfaces is part of the operation The tendons are drawn down and cut short

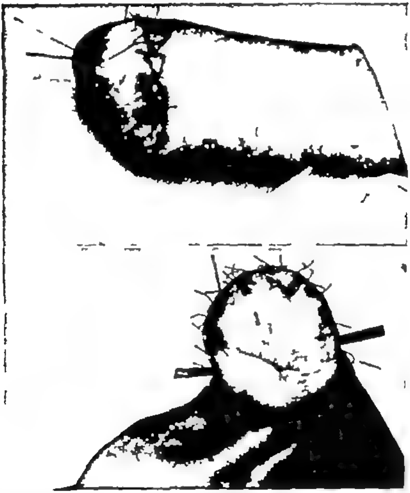


FIG 78 Revision of a heel flap of a Syme s operation showing method adopted to ensure (a) that the heel flap does not slip from its corrected position and (b) drainage.

and the nerves i e anterior tibial and musculo-cutaneous together with the plantar nerves are treated in like manner The nerves must not be left longer than necessary

If preferred, the dorsal incision may be made first the ankle joint opened and the tendo Achillis divided from the front

Amputations through the Foot

The main considerations in amputations of the feet are similar to those pertaining at other sites namely —

(1) The best possible stump for prosthesis should be left irrespective of consideration

be applied so as to leave in its mortice the base of the second metatarsal whilst the projection of the internal cuneiform is removed

(3) CHOPART'S AMPUTATION or amputation at the mid tarsal joint is performed in a similar manner to Lisfranc's (1) A plantar flap with a convex end is marked out reaching on the inner side of the foot from a point immediately behind the tubercle of the scaphoid forwards to within 1 in (2 5 cm) of the root of the toes and terminating on the outer side on a level with the calcaneo-cuboid articulation i e midway between the external malleolus and the styloid process of the fifth metatarsal It should be 1 in (2 5 cm) longer on the inner than on the outer side This plantar flap is first dissected up, including everything down to the bones (2) A dorsal incision is then made with a slightly convex border (3) The joints between the astragalus and scaphoid on the inner side and between the os calcis and cuboid on the outer, are opened from above (4) Disarticulation is then completed and the longer plantar flap is drawn up and united to the dorsal

Chopart's amputation is not on the whole a satisfactory procedure since it consists in the removal of the anterior segment of the arch of the foot the posterior half being left without support As a natural result the head of the astragalus is turned *downwards* causing pressure upon the anterior portion of the stump and a good deal of pain and discomfort whilst the tuberosity of the os calcis is drawn *upwards* by the traction of the tendo Achillis Tripier's amputation has been utilized to prevent such displacement in it an oblique racket is made reaching backwards to the anterior border of the tendo Achillis disarticulation follows at the mid tarsal joint and then the os calcis is sawn across horizontally on a level with the sustentaculum tali so as to leave a broad base of support which is not so likely to become tilted forwards

A still better modification where practicable is to remove the foot on a slightly anterior plane, i.e to leave the scaphoid on the inner side and to divide the cuboid on a level with its anterior border with a saw The skin incisions can be made as for a Chopart The stump left is longer and therefore more easily controlled whilst the attachment of the tibialis posterior is maintained it being relatively easy to give the peroneus longus a new insertion, so that the lateral movements of the foot are in part preserved

(4) PIROGOFF'S AMPUTATION The procedure for this operation is somewhat more complicated than for Syme's whilst the objection to the former remains In this operation a segment of the os calcis is retained in the heel flap and this retained portion of the heel bone is apt to be tilted by the action of the calf muscles which will prevent firm union with the tibia The experience of the Second World War has shown that Pirogoff's method has few indications for adoption and the Syme method is invariably preferred

Trans-metatarsal Amputation

Transverse amputation of the fore-foot through all the metatarsals results in a surprisingly good walking foot although the ease and efficiency of gait decrease progressively at each successively higher level of amputation The tendency towards medial or lateral deviation is absent because the balance of the foot is maintained This is due to the preservation of the normal muscle attachments—tibialis anterior tibialis posterior and the peronei whilst symmetry and shape of the stump are achieved

fifth metatarsal on the outer side (2) The plantar flap is then marked out and should reach forwards from the termination of the former incision as far as the bases of the toes, this, therefore should be longer on the inner side than on the outer (3) The latter flap is dissected up whilst the toes are maintained in full extension

For the first inch (2 5 cm) the skin only is raised, but farther back all the structures in the sole of the foot are included The appearance in the field of dissection, of the peroneus longus tendon will indicate the extent to which the dissection should be carried

FIG 80. Chopart's amputation as a primary amputation with the application of a plaster This is not good practice.

(4) Disarticulation is now performed from the dorsal aspect The plantar flap is sometimes formed at the last stage of the operation having been mapped out in the first instance In such a case the dorsal incision is made first then the metatarsus is disarticulated, and (5) lastly the plantar flap is cut from within outwards.

Hey's procedure is essentially similar to the above with the exception that the projection of the internal cuneiform is sawn across, leaving a more even surface of bone This is infinitely preferable to the simple disarticulation of Lisfranc Hey advised that the three outer joints should be opened as previously described, and then the saw should

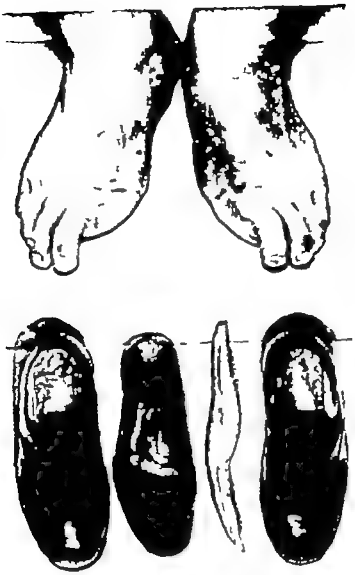


FIG [illegible] Amputation of big toes of both feet with removal of the heads of the metatarsals. Continual problem of fitting satisfactory shoes because of painful stumps.

should never be left when the other four require removal as there will undoubtedly be lateral displacement which is very troublesome

The heads of the metatarsals should always be saved if at all possible

It should be remembered that the joint lies as far behind the web as the apex of the toe is in front of it so that the incision should start further back than might be at first expected

Amputation of a Toe with and without Removal of the Metatarsal Bone

As a rule it is not advisable to perform partial amputation of a toe except of the great toe but instead one should disarticulate at the metatarso phalangeal joint otherwise the stump of the toe is only an inconvenience

For the phalanges and interphalangeal joint the oblique circular incision is indicated whilst for the metatarso-phalangeal joint a racket incision is made The dorsal part of the incision extends down to the bone which is removed subperiosteally

This operation is again performed with the intention of obtaining a long plantar and short dorsal flap

The incision is placed on the dorsum of the foot beginning at the midpoint on the inner aspect and passing convexly across the dorsum immediately distal to the anticipated bone level to a similar point on the outer aspect of the fifth metatarsal The plantar incision starts at the point of origin of the dorsal incision and is convex across the plantar aspect of the foot at a level with the metatarsal heads it passes slightly upwards to unite with the lateral end of the first incision In forming the plantar flap it should be remembered that the cross section of the medial side of the stump is greater in depth than that of the lateral therefore the flap should be much longer on the inner side of the foot A longer dorsal flap may be made if adequate plantar skin is not present but the plantar skin should come up as far as the level of bone section on the inferior surface of the foot since dorsal skin is not suitable for weight bearing If sufficient plantar skin is not available then the metatarsal shafts must be made shorter The dorsal incision is now carried down to bone and the extensor tendons are divided and shortened so that they will retract above the edge of the wound The incision on the plantar surface of the foot is carried down to the bone and the flexor tendons are severed and shortened The plantar skin is dissected slightly above the level of bone section, and a flap is formed consisting of plantar skin subcutaneous fat and a thin layer of plantar muscles The intrinsic muscles of the foot are severed at the level of bone section. The metatarsal bones are now sectioned parallel to the tarso-metatarsal joints and the fifth metatarsal is shortened and bevelled, all loose tags of periosteum being removed Nerves are not isolated they have all been sectioned and allowed to fall back in their beds above the line of bone section Hæmostasis is carefully secured. The skin flaps are approximated without tension trimmed and closed with interrupted sutures. The skin on the sole of the foot like that on the hand, is of a different texture to that of the dorsum it heals slowly so that the sutures should not be removed for about two weeks and even then only alternate sutures until one is certain that union is taking place Not infrequently the skin edges are devitalized and will slough off leaving bone exposed. In this condition the wound should be left to granulate slowly and form a cicatrix which will be parallel to the site of amputation Secondary suture should not be undertaken.

Amputations of Toes

General Considerations. (1) The indications for amputation of the toes are similar to those for amputations of the fingers with the addition that painful deformed toes are more frequently amputated than are deformed fingers The big toe rarely requires amputation the fifth toe however often does Wherever possible one should avoid amputating one or more intervening toes as the remaining toes are pushed together and become clumped and painful. It is good practice if the big toe and one other toe require amputation, to amputate all the toes and make a dorsal scar Patients with all their toes amputated get about comfortably for thirty five to forty years whilst partial amputations of the toes require periodic operations and amputations and give the patient a great deal of trouble

(2) The joint of the first metatarso-phalangeal site is one of the important pivotal points on which the foot rests therefore the great toe should never be amputated or disarticulated except when absolutely essential. A single toe however even a great toe

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In the case of the great and little toe the dorsal portion of the incision is not placed over the middle of the phalanx and the metatarsal bone but towards the middle line of the foot so that the cicatrix may be out of reach of lateral pressure

The best results for removal of the great toe are obtained by Farabeuf's technique —

(1) An incision, starting from over the head of the first metatarsal is made extending down almost to the interphalangeal articulation ; it then crosses the plantar surface of the toe extending to the web of the first and second toe the end of this incision is then carried back to the site of the commencing incision (2) The incisions are deepened, the tendons divided the joints opened and the toe removed (3) The remaining internal flap is brought across the head of the metatarsal bone and leaves a neat cicatrix not exposed to pressure

Disarticulation of the Distal Phalanx of the Great Toe

For a large plantar flap hold the toe between the thumb and first two fingers of the left hand the thumb on the pulp of the toe the fingers on the nail (1) Cut the plantar flap as the toe is thus held. (2) Enter the knife at right angles to the surface just over the head of the proximal phalanx (3) Cut along the side of the toe to the pulp

This incision should be parallel to the phalanx and nearer to the dorsal than the plantar aspect (4) Shape the flap and return to the same point on the opposite side The incision should extend down to the bone (5) Forcibly flex the toe and make an incision across the dorsum by a transverse cut that at once divides the extensor tendon and opens the joint (6) Rotate the toe out divide the internal lateral ligament (7) Rotate it in and divide the external band. Thus disarticulation is complete

The long plantar flap should not be cut by transfixion. If the flap has been well cut the two plantar digital arteries will not be wounded but will be buried in the flap until they anastomose at its free end They may easily be cut accidentally if in dissecting the flap back, the knife is not kept close to the bone They also lie near to the sides of the joint (plantar aspect) and may be easily wounded in careless disarticulation.

Disarticulation of all the Toes (Metatarso-phalangeal Disarticulation)

Each toe may be dealt with separately as follows —

(1) The toe is dorsiflexed, and an incision is carried round it at the place where it emerges from the general cutaneous envelope of the foot When complete all the incisions are united at the webs on the plantar surface The incision runs along the furrow between the digits and the ball of the toes (2) Over the metatarso phalangeal joint of the great and little toes a tarso-lateral incision is made Thus two rectangular flaps are formed (3) The toes are then bent towards the sole (4) The extensor tendons are divided as far back as possible the dorsal and plantar portions of the capsule together with the lateral ligaments are divided, and lastly the plantar tendons are cut across as high as possible

This is an excellent operation and gives gratifying results for badly deformed toes

Amputation or Disarticulation of the Phalanges of the Four Outer Toes

In operating upon the smaller toes the neighbouring digits should be held aside by the assistant

In disarticulation of the second phalanx use the oval or racket incision and proceed precisely as in the corresponding operation in the hand.

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CHAPTER V

AMPUTATIONS OF THE HAND AND FINGERS

"What is it fashioned wondrously that twin born with the brain
Marks man from every meaner thing that bounds across the plain
It is the hand the human hand interpreter of will?
Was ever servant yet so great and so obedient still?
CAMILLA TOULMIN

THE hand is a compact and perceptive manipulative organ To-day the surgeon thinks of it in terms of physiology instead only of anatomy Sensation and function are much more important than anatomical form There is no value in a portion of a digit which is useless, painful or in any way subject to repeated injury In fact such a digit or portion of a digit, may often be a hindrance Couch of Toronto says that the whole matter has been wrongly covered by a blanket rule—" Save all you can Until Bunnell s writing the literature did not contain a great deal of information about the method by

FIG 82. Gunshot wound of hand. *Admittedly a severe injury* The hand had been encased in plaster and the fingers are now permanently stiff and useless.

which the important objectives of preserving and rehabilitating the injured hand may be achieved Very few detailed descriptions of the injured hand can be found There are only occasional references to some elaborate plastic procedure of limited value *During wartime the number of injuries of the hand increases tremendously* The manifold and complicated deformities which then present problems for the orthopedic surgeon are multiplied The fundamental principles of the treatment of an injured hand, to preserve its functions can be stated under three headings *conservative surgical* and *post-operative rehabilitation*

Before any amputation or reconstructive procedure is contemplated a careful appraisement should be made of the hand Consideration must be given to the sensation of the skin and also to such functional potentialities as may exist or be re-developed without further operation

It is important to discuss the situation with the patient having due regard to his employment and to analyse how best the greatest functional use of the hand can be achieved

If the patient intends to return to his previous employment say as a wood machinist (e g a spindle-operator) then a finger which is fixed in extension is a great drawback. Sooner or later most wood workers lose one or more portions of a finger or whole digits

FIG 83. Syme s amputation of right leg Below knee amputation of left. Amputation of most of the digits of the hands (for gunshot wounds) Note the importance to this patient of the preservation of the thumb and proximal portions of the index fingers.

In women particularly one should never lose sight of the cosmetic appearance of the hand for some women are sensitive about a deformity to a degree out of all proportion to its appearance It should therefore remain a fundamental rule to try to preserve or to restore as much of the normal appearance of the hand as possible Often, however a patient will present a well-considered request for the amputation of his finger or portion of a finger

The functional value of a hand can be discussed under three headings apart from sensation which is dealt with in the next chapter

Function of Muscles. Finger action is dependent on three sets of muscles—

(1) The intrinsic muscles which flex the fingers at the metacarpo-phalangeal joint and extend the interphalangeal joints They also abduct and adduct the fingers and so prevent the finger and thumb slipping past each other (e g off a pencil)

(2) The long flexor muscles which flex the metacarpo phalangeal and the inter phalangeal joints

(3) Extensor muscles and tendons *which extend the metacarpo phalangeal joints* and partially extend the interphalangeal joints

The functional value of a hand can be discussed under three headings apart from *sensation*, which is dealt with in the next chapter

Grasp Grasp is the apposition of the fingers acting in unison to the palm of the hand the thenar eminence and the thumb The result of a firm, strong grasp is the grip and the power of the grip is dependent upon the power of the combined action of the intrinsic and the long flexor muscles of the fingers

The preparation for grasping depends on the combined action of the extensors and intrinsic muscles the thumb being abducted from the side of the hand and then opposed to the centre of the palm *This action is dependent upon two groups—the abductor* pollicis muscles which lift the thumb away from the hand and the opponens pollicis which swings the thumb over the centre of the palm The adductor pollicis and the flexor pollicis longus complete the forceful flexion against the fingers For these functions the digits require adequate length normal joint movement and powerful pressure action by the musculature The breadth of the palm of the hand affords stability and balance The palmar interossei muscles are inserted into the bases of the first phalanges and as adductors, are an important factor in affording a good grip to the hand even if only the proximal part of the phalanx remains

Pinch may be described under two headings—pincers and pliers action

Pincers action may be defined as the apposition of the tips of any of the four fingers particularly of the index and middle fingers to the tip of the thumb and is dependent on the integrity of the terminal phalanx together with the pad for its optimum function Picking up small objects is an example of this action

Pliers action consists more in the apposition of the pads of the fingers (not necessarily the tips of the fingers) to the thumb Holding a pencil or a knitting needle are examples of this action The same muscles in the thumb are utilized as in grasping

Pinch action can also be a combination of apposition of several fingers to the thumb as for instance in holding a forceps This action requires an intact metacarpal arch mobility of the carpo metacarpal joints which are being utilized and the normal flexion of the joints

Hook Action. This is the least useful but the simplest to produce The fingers are flexed in varying degrees so that the pads face and become parallel to the palm of the hand This action requires the integrity of the long and short flexor muscles It is usually the last which remains available in an injured hand It is also the action most easily achieved by any artificial appliance pinch being the most difficult and grasp intermediate

The mechanical hand *to be described in Artificial Limbs* achieves these three fundamental actions and therefore constitutes a scientific instrument of high perfection as it approximates to the maximum every possible function in the absence of sensation

Scoop The scoop action is important as a complementary action of the one hand to the other when scooping up—transferring contents from one receptacle to another It will be appreciated that the loss of one or both middle fingers is a drawback in this action

General Consideration of Amputations of the Hand and Fingers

As with major amputations an ideal stump is the aim of the surgeon but in the case of the hand this means not only a mobile painless stump but one where mobility and sensation are of far greater importance than in any other situation

Again in amputating a limb the aim is to achieve the best function of the stump in conjunction with a prosthesis but with a finger there is no prosthesis to be considered, and a cosmetic appliance is very rarely supplied In a badly mutilated hand with a thumb still present but some or all fingers missing an artificial appliance is occasionally provided so as to enable it to function with the thumb and whatever remains of the finger or fingers

When considering amputation each structure in the hand should be given special

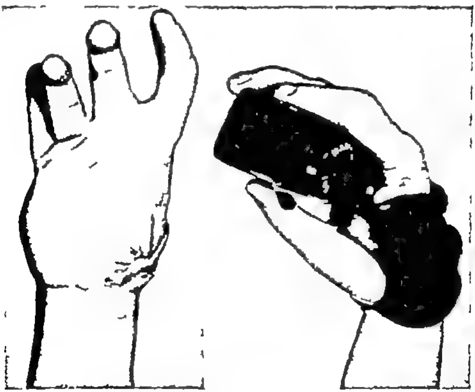

Fig 84 Amputation of the thumb following on a gunshot wound Prosthesis supplied which proved useful for writing (note groove in thumb) etc.

attention skin nerves tendons blood vessels and bone As with most major amputations, a good skin covering is essential especially if that skin is local with good sensation The palmar skin is more sensitive and more abundantly supplied with free nerve endings nerve bulbs and tactile corpuscles than any other part of the hand It is therefore most satisfactory as a covering for the end of the bone It is also more durable than any other skin. Wherever possible long palmar flaps and short dorsal flaps should be cut As with amputations of the limbs so in the amputation of the fingers there should be sufficient skin to cover the end of the bone without tension and without loss of mobility

If the skin flaps are short or tight or fixed it is wise to shorten the bone further and thus enable it to be covered without tension Treatment of tendons is important in finger amputations, and it should be remembered that tendons have a poor blood

supply derived from blood vessels of the tendon sheath and that each phalanx is moved by its own tendon Fingers are flexed at the metacarpo phalangeal joints by the lumbricales and interossei muscles, which also extend the interphalangeal joints through the common extensor expansion The second phalanges and secondarily the first phalanges are flexed by the flexor sublimis digitorum but both the proximal and distal phalanges are flexed by the flexor digitorum profundus

Since each phalanx has its individual muscle supply it is *unnecessary to suture the tendons over the end of the bone* in the manner usually practised as this produces stiffness Moreover since the blood supply of the tendons is poor the tendon is apt to slough if the wound does not heal by first intention If it heals it gives the finger a club-shaped appearance and is apt to diminish, rather than add to its strength Therefore both the flexor and extensor tendons are cut and allowed to retract when there is no infection present

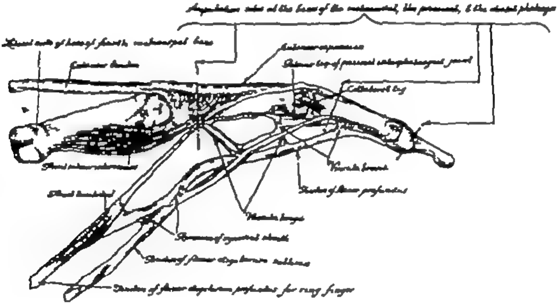

FIG 85 Elective sites for amputation of the phalanges having regard to the important tendon insertions.

They do not form adhesions and do not impair movement If possible the tendons should be pulled out before section The digital nerves should be drawn taut sectioned, and left to retract slightly away from the suture line The occurrence of painful neuromata can be minimized by preventing scar tissue, which may result from infection around nerve endings The amputation should always be performed in a clean field, well away from the devitalized tissue and the nerve replaced in a healthy bed The digital arteries should be ligated with fine catgut (000)

The bone should be neatly sectioned not crushed, either with bone forceps or a metacarpal saw If the end of the bone is inclined to be bulbous it should be trimmed with a file The flexor and extensor tendons are inserted into the bases of the phalanges and if possible the available portion of these tendons should be preserved by amputation distal to their insertions If disarticulation at a joint is inevitable the bulbous extremity

of the bone should be tapered with sharp bone forceps because the width of the condyle makes the ultimate result unsightly

Certain additional anatomical facts have to be borne in mind when amputating a digit —

(1) POSITION OF JOINTS The joints do not correspond with the prominence of the knuckles which are formed by the heads of the metacarpals and bases of the proximal phalanges The joints are situated respectively ½ ¼ and ⅛ in distal to the prominence of the knuckles starting at the proximal joint

(2) POSITION OF DIGITAL NERVES These lie on each side of the finger immediately in front of the digital artery and both artery and nerve lie slightly anterior to the mid plane In amputations which are proximal to the distal inter phalangeal joint it is important to identify and follow these nerves in order to divide them as high up as possible

(3) THE FLEXOR TENDONS The four tendons of the flexor profundus digitorum are inserted one to each base of the terminal phalanges after perforating the four tendons of the flexor sublimis digitorum the tendons of which split and are inserted into the sides of the base of the second phalanx of each finger

These tendons are attached to the anterior surfaces of the phalanges by fibrous bands (vincula) which may prevent the cut tendons from retracting If a flexor tendon is cut proximal to the second phalanx where it is attached to the middle of the bone the tendon is free to retract If the tendon sheath is infected both sheath and tendon may easily carry infection into the proximal tissues Therefore the tendon should be held before division and fixed to the periosteum by a stitch This precaution is not necessary in amputation for infection distal to the second phalanx

(4) THE TENDON OF THE EXTENSOR COMMUNIS DIGITORUM replaces the dorsal ligaments of the interphalangeal joints

The following surgical points should be attended to when amputating a phalanx —

(1) Amputation is preferable to disarticulation, i e it is advisable to remove a part or parts either by sawing or with a sharp bone-cutting forceps rather than by going through the joint

(2) When disarticulation has to be performed it is unnecessary to stitch the flexor and extensor tendons over the face of the stump

(3) As much as possible of the thumb should always be preserved Practically no part of the thumb can be useless

(4) The scar should be on the dorsum of the fingers or hand, so as to escape possible pressure

Amputation of the Thumb The thumb is the most important single digit in the hand. The only indications for amputation are gangrene and the rare conditions when the thumb becomes a hindrance e g flexion contracture of a useless thumb which presses against and ulcerates the index finger by necrosis in rheumatoid arthritis (see Fig 86) Even the smallest portion is of the utmost use Without a thumb the power of grasp and pinch is lost and the value of the hand is lessened to an extreme degree Every effort should be made therefore to save as much as possible of this important entity even if it becomes fixed and acts only as a post for opposition of the other fingers There are many plastic procedures for reconstructing a thumb and if amputation has been resorted to as much as possible of the length should be saved

FIG 86. A case of long-standing rheumatoid arthritis in which the thumb had ulcerated and embedded itself in the index finger. The hand was useless. The thumb was removed because of pain.

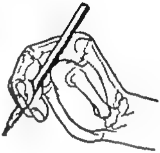

FIG 87 Even the shortest stump of the thumb is of great utility
[*After Couch.*

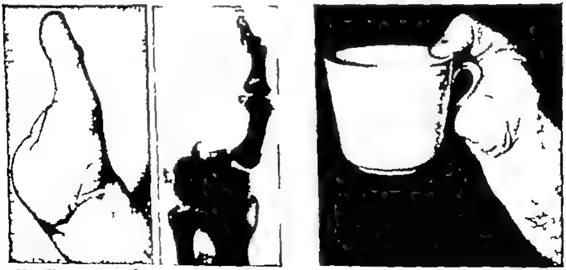

FIG 88 Photographs of a case operated upon in 1911 Four fingers, their metacarpal bones, the trapezium and the trapezoid were removed. The first metacarpal now articulates with the scaphoid.

[*Hamilton Bailey "Surgery of Modern Warfare." E. and S. Livingstone.*

Index Finger The loss of part or all of the distal phalanx of the index finger is no great handicap to the average individual If on the other hand a violinist loses the terminal phalanx of his or her digit this interferes with playing and therefore results in loss of earning capacity Should injury or disease necessitate an amputation proximal to the distal interphalangeal joint as a general rule the entire finger should not be sacrificed because the patient can learn to use the short proximal phalanx of the index finger if the basal insertions of the tendons are intact Except in the case of artisans and labourers the head of the metacarpal may be removed It may improve the cosmetic appearance but at the sacrifice of strength For labourers the head should be left as it widens the hand preserves the transverse metacarpal ligament and thus adds to the stability and strength

Occasionally the metacarpal head tends to be pushed backwards and becomes unsightly If it is removed the remaining adjacent fingers are adducted and the hand is weakened. This may be prevented by using the distal part of the phalanx as a bail graft

A study of everyday uses of the fingers of people engaged in the lighter occupations such as typists and other keyboard operators, etc shows that the index and middle fingers are those most frequently employed

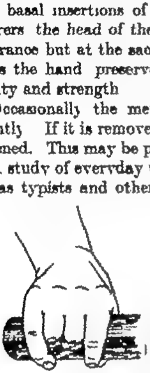

FIG 89 A good amputation. The middle stumps increase the grasp and prevent approximation of the remaining digits.

[After Couch.

It is false reasoning to believe that an amputation of the head of the first metacarpal or even the fifth metacarpal gives the hand a better cosmetic appearance Amputations of the fingers and parts of fingers are not uncommon and people ignore them, but if there is any deformity for which concealment is attempted more attention is drawn towards it

The ring and little fingers valuable to craftsmen and labourers can be more *readily sacrificed* in those whose occupation requires delicate and precise movements

Scoop action is an important function of the hand both with the hand used singly and as a complement to the other hand Loss of the middle or ring finger of either hand seriously interferes with its action as a scoop

The index and middle fingers are far more powerful than the ring and little fingers and more sensitive For a good grip it is essential to have strong digits which can press against the palm of the hand The gripping surfaces should therefore be painless and, if possible without scars

In the case of the middle and ring fingers amputations at all levels distal to the first interphalangeal joint are satisfactory

A long stump gives strength to the hand and prevents the adjacent fingers falling together Contrary to what is taught amputations through the first phalanx, the metacarpo phalangeal joints and the proximal interphalangeal joints do leave stumps which are of value Amputation proximal to the metacarpo-phalangeal joint is not to be encouraged, as there is a tendency for the remaining digits to be pulled together thus displacing the metacarpal shaft of the amputated digit backwards In any case by preserving the insertions of the interosseous and limb muscles the power of the grip is left

In the case of a manual worker with a flexion contracture of the index or little finger, these fingers can remain out of the grasp if so desired

Amputation of the ring finger and of the little finger weaken the leverage because they act as a fulcrum e g in the case of a workman holding a spanner

Indications for Amputations

Hand and Fingers. It is unwise to make dogmatic statements concerning amputations of the fingers Each case should be judged according to the nature of the lesion and the presence or absence of the remaining digits due consideration being given to the occupation of the patient If possible, in the case of an artisan preserve the fourth and fifth digits It is difficult if not impossible for a workman to hold a hammer or other tool satisfactorily when these fingers have been amputated If a phalanx, amputated at the base proves of little value, re-amputation can always be made at a later date After returning a hand injury to work it is surprising to note the amount of functional improvement that takes place within six months Without sufficient tissue no useful function can be achieved subsequently Therefore, as a primary line of treatment conservation of tissue must be the keynote in surgery of the fingers and hands

(i) ACUTE TRAUMA It is surprising how pronounced is the power of recovery in the hand so that it is better to avoid immediate amputation unless the finger is literally hanging by a thread Operation therefore should be postponed until there is unmistakable evidence that the finger or part of it will not survive Unless the injury is complicated by sepsis no formal amputation should be done for such injuries but the doomed portion should be separated at the point at which injury has occurred the bone trimmed and the skin cover fashioned by flaps

Exceptions (a) Severe compound fractures involving joints which are irreparably damaged and soft tissues which have been lacerated In such injuries when there is *unmistakable evidence* that no useful function is to be achieved amputation may be considered (b) When several structures in the finger have been so severed as to be beyond repair e g loss of skin, that is a degloved hand associated with a fracture severed tendons and the principal digital nerves

(ii) GANGRENE Chemical or thermal (electrical) gangrene of the tips of the fingers and hands is more commonly seen than gangrene which is associated with peripheral vascular disease such as Raynaud s disease Buerger s disease or arteriosclerosis

The necrotic tips should be kept dry and infection avoided If infection ensues it is sometimes necessary to trephine the nail or even occasionally to remove it for drainage If the gangrene remains dry and painless the necrotic portion slowly separates Amputation is necessary to assist this process and also in the cases where the gangrene is painful

(iii) INFECTIONS OF THE HAND In sepsis early amputation need not be considered for with the use of chemotherapy and antibiotics it is wise to defer the question of amputation until the damaged septic area has been given an opportunity to recover and then to amputate only when the involved parts have failed to respond to treatment

In chronic infections which have progressed in spite of chemotherapy and antibiotics the hand sometimes remains merely a bag of pus and disorganized tissue In these cases it is clear that no useful function will remain

Infected fingers which have passed beyond the acute stage and in which the infection has been controlled may be considered for amputation if the end result is complete loss

FIG. 90: Severely lacerated hands and fingers involving skin, muscle, tendon and bone. Result after conservative treatment.

[*By courtesy of M. J. Ellsworth Laing of Plastic and Oral Surgery Centre, Salisbury*

of function and a painful, hypersensitive finger A painful hypersensitive finger may remain in this state until the anxiety state of the patient is relieved when the claim is settled

Amputation of the little finger also seriously weakens the leverage power by limiting the length of the span of the hand

Fingers which have become involved in an infective process leading to osteomyelitis and suppurative arthritis should be treated with appropriate antibiotics Occasionally

Fig 91 A case of thrombo-angiitis obliterans with gangrene involving the tip of the ring finger the distal two phalanges of the middle finger and the end of the thumb The index finger has already been amputated.

it may be found necessary to amputate a portion of a digit or even a whole digit when it is found that no improvement is possible even with surgical drainage Sometimes a finger tip can be saved by removal of the terminal phalanx only and filleting the infected segment Amputation in such cases shortens convalescence it allows mobilization of the remaining fingers while it removes a painful liability

(iv) Deformities Stiff and useless fingers which result from both injury and sepsis form one of the most common indications for amputation

Such a finger may be fixed in flexion or extension If fixed in extension it stands out like a rigid rod, fails to contribute anything useful to the hand in general and by preventing the other fingers access to surrounding objects impairs their function

Fingers which should be considered for amputation are those fixed in flexion—usually the result of conservation of digits which have become ankylosed following an infection or trauma or both—which the surgeon has rightly preserved as long as possible Even then however a finger fixed in moderate flexion may be well worth keeping especially the index finger since this position is the position of function For example it has been possible for a surgeon to carry on his work with such a deformity

Occasionally such deformities are accompanied by sensitive scars and these may be regarded as a definite indication for amputation There are cases in which the flexor tendons are fixed by adhesions so that their action is greatly limited or even totally abolished, but in which the bands themselves remain loose and supple allowing passive

Fig 9 Amputation of the left hand and forearm. The right hand has only mis-shapen index finger and a post as a thumb. It is important to preserve this in such a case

flexion to take place Although amputation may be indicated in these cases the patient s personal inclination and his employment should be studied

There are operations for the substitution of free tendon transplants for a disorganized tendon but the patient may not be inclined to continue along a doubtful line for a further period When reconstructive operations fail and it is futile to persevere amputation is justified A long-standing Dupuytren s contracture which has failed to respond to treatment may also occasionally require amputation

Apart from these indications tuberculous dactylitis in adults may occasionally necessitate an amputation.

(v) Tumours (*a*) *Benign* In cases where a simple growth exists and the function has been destroyed the finger involved is not only a hindrance to the remaining fingers but is unsightly

(*b*) *Malignant* Epithelioma and melanoma are well-defined indications for amputation

We owe a great deal to Sterling Bunnell for he has taught us that, with careful surgery suture of such structures as digital nerves very often gives excellent functional results where previously amputation was inevitable In our zeal however to preserve

FIG. 93 Recurrent fibroma of the terminal phalanx of a finger which had previously been operated on. It had involved the nail bed and was causing pain. Amputation of the terminal phalanx.

FIG. 94 Squamous epithelioma of the base of the ring finger Deep X ray therapy failed. Followed by amputation.

a finger or part of a finger we should not lose sight of the possible loss of working time and the inconvenience which can be avoided by a well planned amputation where such is indicated.

In cases of damage to the finger tips it is important that a well padded tactile surface is restored A large tender avascular scar covering the tip of a finger is to be avoided at all costs because the frequent presence of pain and tenderness prevents any function of the finger

These tender scars are extremely difficult to eradicate They are the origin of a causalgic finger tip which is most resistant to treatment True causalgia originating in the fingers is extremely rare Hugh Griffiths in a personal communication comments that he has only seen this condition in civil practice twice in forty years It is desirable to forfeit a little additional bone so that the soft tactile pad on the front of the finger can be sutured to the dorsum, producing a well-cushioned tactile pad

Technique of Amputation of Finger Distal to the Metacarpo phalangeal Joint. A racket incision should be made the handle of the racket beginning on the dorsum of the hand, just above the centre of the joint and extending downwards for ¼ in (0·6 cm) below the level of the web The incision should be carried round the finger its lateral parts being extended down to the bone The flexor sheath and its tendons are then cut proximal to their insertions Amputation is completed by severing the extensor tendons distal to their insertions If a disarticulation at the metacarpo phalangeal joint is inevitable the head of the metacarpal bone should not be removed except in the case of the index and little fingers when it may be neatly bevelled In these cases the incision of the handle of the racket should be prolonged upwards for about 1 in (2 5 cm) It is also necessary to divide the transverse metacarpal ligament

Amputation of a Phalanx. The part to be removed is held between the index finger and the thumb and bent to a right angle at the inter phalangeal joint

Amputation distal to the insertions of the tendons is preferable to disarticulation An incision convex distally is made on the dorsal aspect and continued on to the palmar aspect making rectangular flaps the palmar somewhat longer than the dorsal, until the two incisions are connected up the superficial tissues and the extensor tendon are divided, the bone snipped across and a palmar flap dissected off this can then be neatly approximated to the dorsal flap

The palmar and dorsal flaps are dissected upwards The superficial tissues and the flexor and extensor tendons are then divided and the bone is denuded at the site where it is proposed to amputate and snipped across In the case of a disarticulation the capsular ligaments are divided and the joint surfaces separated. The tourniquet is then removed and any bleeding points from the digital vessels are caught up and ligated The palmar flap can then be brought backwards and neatly approximated to the dorsal flap

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CHAPTER VI

AMPUTATIONS FOR GANGRENE AND VASCULAR DISEASES

It is dangerous to disturb the body violently whether it be by starvation or by feeding by making it hot or cold or in any way whatsoever All excesses are inimical to nature It is safer to proceed a little at a time especially when changing from one regimen to another

HIPPOCRATES

General Considerations

GANGRENE* is generally classified into two types—dry and moist Although the differentiation between dry and moist gangrene is sometimes very difficult the difference in these two groups depends finally upon the amount of fluid present in the tissue There are few things in life however that can be termed either black or white for they are very often merely a shade of grey Generally speaking then if there is interference with the arterial circulation whereby the blood supply is cut off the gangrene will be dry but if there is infection or extensive venous occlusion, or both the gangrene will be progressively softer and moist

Dry gangrene is found in the occlusive affections of the arteries of the limbs where the blood supply is gradually cut off There is little fluid in the tissue and the skin is dry cold and tallowy Hæmoglobin diffuses out along the capillaries and small veins and imparts a reddish purple staining to the affected portion The colour slowly changes to brownish red and then finally to black, due to gradual breakdown of the hæmoglobin The part shrinks and becomes drier and mummified The junction between the living and dead tissue is well defined and is termed the line of demarcation The living tissue shows a well marked inflammatory reaction to this foreign body at its distal end. A process of slow ulceration occurs through the soft tissues down to the bone e g around a finger or toe It may stop there or it may progress slowly involving another toe and then the dorsum of the foot and then more slowly but relentlessly onward up the limb This gangrenous part may at any stage be cast off and the patient left with a conical stump uncovered by skin and terminating in a great deal of granulation tissue This process may be seen in simple occlusive vascular disease where the lumen of a vessel has been slowly obliterated

Moist Gangrene. If during this process the skin surface is damaged, then infection will become superimposed upon the gangrenous process It is then that the transformation from dry to moist gangrene occurs If on the other hand there is sudden occlusion of the blood supply particularly of the veins with accumulation of metabolites resulting in vasodilation and the reflux of venous blood into the area, œdema of the part ensues This damaged area with no blood supply forms an admirable nidus for the growth of pathogenic organisms The damaged part of the limb now becomes œdematous while blebs of fluid form in the skin and infection occurs in these blebs The tissue dies and

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becomes a putrid, semi-solid foul-smelling mass In this process there is no line of demarcation.

The Pathology of some Peripheral Vascular Diseases that may cause Gangrene

Having briefly described the two main types of gangrene we must now consider in more detail the ætiology of its production and its management · For simplicity the causes of gangrene can be sub-divided into —

Classification of Peripheral Gangrene

(1) INFECTIVE GANGRENE
- (a) Non-specific—Diabetes—young diabetics
- (b) Specific—Gas gangrene

(2) GANGRENE DUE TO OCCLUSIVE VASCULAR DISEASE
- (A) *By obstruction of the lumen*
  - (1) *Degenerative conditions*
    - (a) Senile obliterative arteritis
      - (i) Diffuse
      - (ii) With popliteal thrombosis
      - (iii) With femoral thrombosis
    - (b) Peripheral obliterative arteritis
      - (i) Older group (70–80)
      - (ii) Younger group (30–40)
  - (2) *Inflammatory conditions*
    - Juvenile obliterative arteritis (Buerger's disease)
  - (3) *Diabetic gangrene*
    - (a) Primary—young group
    - (b) Secondary—old group
  - (4) *Primary popliteal thrombosis*
  - (5) *Arterial embolism*
- (B) *By arterial spasm*
  - Raynaud's phenomenon
    - (a) Primary—due to local blood vessel fault (sensitivity to cold)
    - (b) Secondary—due to effects of cold on diseased vessels

(3) TRAUMATIC GANGRENE.
- (A) Effect of cold
  - (i) Frost-bite
  - (ii) Immersion foot and Trench foot
- (B) Sudden occlusion
  - (i) Direct injury of vessels
  - (ii) Concomitant to soft tissue or bony injury
  - (iii) Operative trauma
    - (a) Accidental
    - (b) Deliberate ligation
- (C) Maintained occlusion
  - (i) Tight plaster or splint gangrene
  - (ii) Tourniquet gangrene

Fig 93 Compound fracture of tibia complicated by gas abscesses.

[*Hamilton Bailey and McNeill Love "Surgery of Modern Warfare" Part II 3rd Edn E and S Livingstone*

A B C

Fig 9 Gas gangrene. A Normal muscle. B "Red Death —note the cavitation by bubbles of gas. C Black death.

[*After Sir Cuthbert W Wallace. "Surgery of Modern Warfare" Hamilton Bailey Part II 3rd Edn., E and S Livingstone.*

[*To face p.* 119.

1. Infective Gangrene

(*a*) NON SPECIFIC INFECTIVE GANGRENE Diabetes is the one condition in which infective gangrene is commonly seen and here several factors come into play *Early on* in the progress of the disease well marked vascular occlusion occurs, a high sugar level is present in the tissues and, as this is an ideal culture medium, in many instances there is infection followed by moist gangrene

Gas Gangrene

(*b*) SPECIFIC INFECTIVE GANGRENE Here there is infection of tissues by gas forming organisms A survey of the literature reveals that gas gangrene is a very old disease Hippocrates described very vividly a *fulminating infection of the leg* which appears to have been gas gangrene and Celsus also seems to have recognized this disease In 1593 Fabricius Hildanus published one of the earliest clinical descriptions and expressed his belief that the principle cause of this terrible ill is some venomous tumour which Nature has driven into these people Later Dupuytren described a condition of ' spontaneous emphysema occurring in trauma and resulting in rapid decomposition of the injured part

There is evidence that the incidence of gas gangrene has been significantly increased during more recent times presumably because of the greater number of wounds which have been produced in modern wars by high-explosive shells, bombs and land mines According to Zeissler 100 000 died of this complication during the First World War In the more recent Ethiopian and Spanish Wars gas gangrene was relatively infrequent but the advent of active fighting in Europe in 1939 and 1940 increased the number of cases and 1 76 per cent of all contaminated wounds are said to have been complicated by gas gangrene

In civilian life gas gangrene is comparatively rare Again it is usually a complication of a compound fracture or some penetrating injury

Predisposing Factors. The location of the wound is of considerable importance since it is known that some tissues of the body have feeble powers of resistance and also that the resistance of the tissues varies considerably with their location The muscular areas of the thigh calf and buttock are especially susceptible while the face scalp back and thorax are affected infrequently

Disintegration of tissue is caused by saccharolytic proteolytic and hæmolytic action of bacteria introduced either from the skin surface or by a penetrating injury to muscle Fluid collects within the sarcolemma sheath and forms a culture medium for the anaerobic bacilli These produce gas and the fluid products are absorbed increasing the toxæmia

Gas gangrene is said to occur more frequently in colder rather than warmer months

Prophylaxis Treatment. Prophylaxis as well as the treatment of this condition must be stressed. Early and adequate surgery is still the most effective means of preventing gas gangrene for not only does it eliminate the conditions necessary for the propagation of the bacteria but it also removes most of the contaminating infectious matter Adequate surgery implies early and meticulous excision of all dead tissues removal of dirt clothing and other foreign material the preservation of the blood supply the relief of tension and sufficient drainage

It is now agreed that operation is the most effective means of treating gas gangrene,

together with anti-gas gangrene serum and intensive chemotherapy penicillin, terramycin or other antibiotic

If amputation becomes necessary in gas gangrene it should be undertaken at a level well above the infection. Flaps should be cut and then lightly sutured (three or four sutures) over the cut end of the muscle and bone. The stump should be drained and appropriate antibiotics administered until the infection is known to have been overcome

2 Gangrene due to Occlusive Vascular Disease

Despite the increasing attention given to the treatment of vascular diseases and irrespective of their aetiology gangrene from cardio-vascular disease is a common reason for amputation to-day In considering vascular diseases of the limbs the term symptomatic of cardio vascular disease has been chosen but it must be remembered that this may be only one manifestation of a generalized vascular condition involving probably the heart the kidneys and other organs of the body not merely vascular disease of the limbs

These vascular diseases are best considered in the following groups —

By obstruction of the lumen

By arterial spasm

DEGENERATIVE AND INFLAMMATORY DISEASES In the text books of pathology one still finds these diseases described each in its watertight compartment and being dealt with in a general way with macroscopic and microscopic appearance of each separate disease These facts alone do not suffice clinically It is impossible to treat the diseased vessels as they must remain with the patient but one must know where the occlusion is situated and what is likely to be the state of the collateral circulation in the patient who has gangrene or is at the moment only complaining of the subjective symptoms of the disease For this reason the pathology of one small part is of little value The site the collaterals and the prognosis of each part must be assessed

There is some controversy and confusion over the terminology of these diseases

Leriche studied a large series of cases with arterial disease and emphasized the fact that they can be divided into a young group occurring before the age of thirty five such as Buerger s disease (thrombo-angitis obliterans) a group occurring over fifty where arterio-sclerosis is the causative factor and a group between these two which apparently showed some of the features of both groups This has also been confirmed by others studying large groups but some further yardstick is required by which these diseases may be classified Boyd has reviewed the clinical manifestations and the arteriographic findings of a large series of cases and classified them as below He and his colleagues worked out this classification from findings which are not only of academic interest but also indicate the treatment in each condition —

(1) Arterio sclerosis senile obliterative arteritis (Diffuse)
(2) Secondary thrombosis (popliteal. femoral, peripheral)
(3) Juvenile obliterative endarteritis (Buerger s disease) thrombo-angitis obliterans
(4) Primary thrombosis of the popliteal artery

In describing these conditions it is well to consider the arterial plan of the limb The vessels may be sub-divided anatomically physiologically and pathologically into three groups —

(a) Primary group—the femoral and popliteal

(b) Secondary group—the anterior and posterior tibial and

(c) Tertiary group—the arterial bed

1 ARTERIO SCLEROSIS OR SENILE OBLITERATIVE ARTERITIS The great increase in the number of old people makes this the commonest cause of ischaemia and gangrene and thus the commonest reason for amputation to-day

Before considering the lesions microscopically one must consider the general pattern of the senile type of the disease First with occlusion of the primary group a block as high up as this is by no means the immediate cause of peripheral gangrene

The arterial anastomosis may well be sufficient around the knee to provide an adequate circulation below it There will be the symptoms of claudication and cold feet

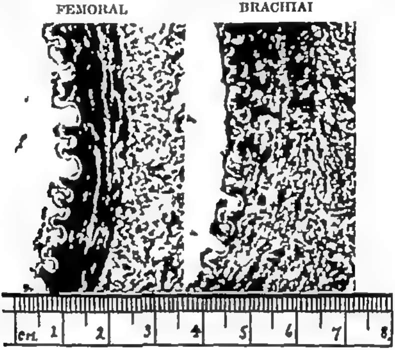

FIG [illegible] The quantity of muscle in a vessel increases relatively as the vessel reaches the periphery of the limb The aorta itself is composed almost entirely of elastic tissue. The femoral artery has a larger quantity of muscle tissue. The upper limb vessel coats have relatively more muscle tissue than the lower limb vessels. *This accounts for the greater degree of vaso-motor control of the lower limb*

[S M Cohen, Postgraduate Medical Journal.

etc but gangrene may be staved off Here conservative measures are of great value to increase the supply

Peripheral Arterio-sclerosis A certain number of patients usually in the 70–80 age group present with pregangrene of a toe or several toes In these cases there is a marked cyanosis of all the toes and sometimes the fore foot The pulps are withered the skin atrophic and shiny and the circulatory return sluggish There may be multiple perniotic lesions or gangrene The pulses at the ankles however are full and the oscillometer shows good pulsation at this level There is often an ischaemic metatarsalgia This condition is due to a peripheral type of arterio-sclerosis and usually only means the loss of a digit Fingers may be similarly affected Occasionally an identical condition is seen in men between 30–40 which does not seem related to juvenile obliterative arteritis (Buerger's disease) and may be placed in a special category It differs from true juvenile obliterative arteritis inasmuch as there is no phlebitis or fungus infection and normally no tendency to progress beyond ankle level It differs from true diffuse obliterative

FIG. 99 Arterio-sclerotic disease of digital vessels of hand in woman aged 73. Full radial and ulnar pulses present Forearm amputation became necessary Death later from coronary thrombosis.
[S. Cohen, *Postgraduate Medical Journal*.

arteritis in the younger man inasmuch as the main vessels are normal and there is no evidence of general arterial involvement Fingers may be involved as evidenced by Raynaud's phenomenon.

Elderly people often have these cold ischaemic feet for years ; but the balance of blood supply and the needs of the tissues may be disturbed by a paronychia or fissures in the skin between the toes leading to fungal or bacterial infection, and gangrene may be precipitated.

If on the other hand, *the arteries of the secondary group are affected by the following*

(a) an initial block in that segment (b) the lodgment of a clot (c) an atheromatous plaque from above, or (d) as an extension from a popliteal thrombosis then the supply of blood below will almost certainly be insufficient and gangrene will ensue

So we have two types of lesion In one symptoms are present but gangrene although always a danger does not appear immediately in the other, either alone or in association with the first gangrene invariably follows

The ætiology of these pathological conditions has been the subject of much research and argument but as yet one cannot quote any definite factors Pathologically two distinct processes are involved —

Atheroma begins with small plaques of thickening in the intima As the lesion progresses one sees yellow plaques developing beneath the intimal thickening These yellow plaques infiltrate the deeper layer of the intima and are composed of lipoids associated with cholesterol crystals Slowly the whitened thickened intima gives way and the degenerating yellow fatty material is discharged into the circulation There is thus left an irregular ulcer on the wall of the vessel—an atheromatous ulcer Slowly the whole vessel becomes thickened by fibrosis and there is some deposition of calcium salts around the edges of the ulcer Clinically the vessel becomes harder and rigid. On arteriography the vessel presents an irregular beaded appearance and as a radiograph along the course of the vessel may show irregular patches of calcification

2 SECONDARY THROMBOSIS IN THE POPLITEAL AND FEMORAL VESSELS These forms of thrombosis are secondary to senile obliterative arteritis This condition is not necessarily found in old people but may occur in the age groups of thirty to forty and even younger Marked atheroma has been recorded even in very young people Popliteal thrombosis occurs in the popliteal artery behind the knee where the vessel is attached to the capsule of the joint by a fibrous band and it may progress proximally as far as the adductor opening for the femoral artery

The cause of the condition is probably repeated minor injuries due to flexion and extension of the knee joint and the habit so many people have of crossing their legs when sitting The effect of this thrombosis will naturally depend upon the response of the collateral circulation to the obstruction of the vessel, and this depends on whether the thrombosis has been gradual or sudden If it has been sudden severe ischæmia and gangrene result and, conversely if it has been gradual over a long period the collateral circulation has had an opportunity to establish itself

Femoral thrombosis occurs in the superficial femoral artery begins at the adductor opening and advances to the origin of the profunda femoris artery This form of thrombosis is determined in the same way as popliteal thrombosis If the block is higher the effects of the thrombosis on the peripheral circulation are less severe

The symptoms of both these conditions are claudication with pain in the calf atrophy of the muscles of the leg and nutritional changes in the skin and nails Gangrene of the limb is not uncommon. It has been demonstrated by Boyd and others that the arteriographic picture shows beading of the blood vessel or a complete block either at the opening in the adductor canal or in the popliteal fossa Oscillometric readings give a good clinical indication as to the level of the obstruction while the usual clinical features of coldness of the feet and toes and cyanosis indicate the degree of obstruction

3 THROMBO ANGIITIS OBLITERANS — JUVENILE OBLITERATIVE ENDARTERITIS (BUERGER S DISEASE) This group occurs under the age of thirty five Von Winiwarter,

in 1879 first described this type of lesion, and later Leo Buerger in 1924 elaborated the original findings and the condition has since been known as Buerger's disease In the original account he describes lesions which we can now divide off from the large group which present the features discussed below

This disease *juvenile obliterative endarteritis* is an occlusive vascular lesion of obscure origin Before proceeding with a description there are two factors that must be mentioned (*a*) it is said to be found more frequently in Hebrews than in others and (*b*) tobacco seems to have a deleterious effect upon its course The latter however is a doubtful factor and the vaso-spastic action of nicotine in aggravating the pathological condition is probably of greater importance Most authorities now agree that nicotine is not an ætiological factor in the disease but they are divided as to the effect on its course Most American authorities including Silbert believe implicitly that total abstinence from tobacco will halt the progress of the disease if not cause considerable regression. Considerable support is given to this view by the work of Grace Roth at the Mayo Clinic In England however we are by no means convinced of this It can be shown that a cigarette smoked produces peripheral vasoconstriction but it is equally true that this is followed by vasodilation which is not affected by a second cigarette in some cases To argue that a temporary constrictor will produce permanent harm is like saying that a temporary vasodilator like nicotinic acid will produce a permanent cure of vasospastic conditions The reasonable view to take is that if the viability of a digit or limb is threatened it is wise to forbid smoking until the acute emergency has passed and the collateral supply is established Even temporary constriction is to be avoided under these circumstances

The former statement that it is more frequent in Jews is open to doubt In my cases this is certainly not so and in connection with Buerger's original cases it should perhaps be remembered that Leo Buerger practised at Mount Sinai Hospital in New York, i e in a Jewish quarter in a city a third of whose population were Jews

All cases of arterial insufficiency in young people (under 35 to 40) were formerly classified as Buerger's disease Boyd has analysed this large group and certain distinct entities have emerged (*a*) The clinically distinct cases of Buerger's disease with a history of migrating superficial phlebitis fungus infection of the toes and evidence of peripheral ischæmia in lower limbs only , (*b*) cases in which there is no history of fungus infection or phlebitis and in which there is evidence of involvement of both upper and lower limbs These are cases of diffuse obliterative arteritis occurring in a younger age group and differ in no respect from the elder type (*c*) cases of intermittent claudication in young men

This symptom is not common in Buerger's disease as the thrombosis commences peripherally and extends proximally slowly to the ankle level producing early ischæmia of the toes—the presenting symptom—while the extension from the ankle to the popliteal level is more rapid and accompanied by peripheral gangrene Gangrene therefore often occurs before claudication has the chance to appear It is therefore preferable to confine the term juvenile obliterative arteritis to the first of these syndromes and discard the term Buerger's disease and the implied inaccuracies of diagnosis

The disease begins in the small arteries of the foot and gradually ascends to involve the popliteal and more proximal vessels As it begins in the small vessels of the feet the first complaint is cramp like pain in the feet which is often diagnosed as chronic foot strain, or other orthopædic ailment Later when the symptoms of intermittent claudica

tion and then of gangrene appear the correct diagnosis becomes obvious The disease is progressive and one leg or possibly both legs may need amputation within five years of its onset The condition is usually bilateral A patchy migrating phlebitis may precede all the other manifestations Clinically, the ischæmia may produce pain during rest

FIG 100 Thrombo-angiitis obliterans. Section of posterior tibial artery and vein showing organization and recanalization. The dilated vasa vasorum show as clear spaces in the media. Vein and artery are closely bound together by the abundant adjacent fibrous tissue

claudication during walking also described as angina cruris or nutritional changes in the feet such as early ulceration followed by gangrene

It can be demonstrated pathologically that the neuro vascular bundle is a thick fibrous cord The inflammatory hypertrophy involves the arteries the veins and may generally affect all tissues near the vessels The vessel is thickened and contains an organizing thrombus Microscopically in the early stages the adventitia may be seen to be infiltrated with polymorpho nuclear leucocytes the intima is also thickened, and the lumen contains a clot in various stages of organization and shows attempts at recanalization. Characteristically focal accumulations of giant cells are found in the central part of the thrombus Later the whole neuro vascular bundle is found fibrosed and in addition to the changes mentioned above the vessel shows a recanalized thrombus

These findings were described by Buerger from amputation specimens But difficulty has always been found in separating the components of the neuro vascular bundle when amputating for gangrene of some chronicity It has been suggested that the fibrosis is due to the infection travelling in the peri vascular lymphatics Whether this produces the pathological conditions found is of course open to speculation

T W A case of thrombo-angiitis obliterans A male aged 38.

This patient complained of pain in his left calf in 1942 and this was followed by gangrene of the big toe and the second toe of the left foot in 1950

In July 1950 a left-sided lumbar sympathectomy was performed and in September 1950 the second toe of the left foot was amputated and the big toe was amputated in October 1950

The wound healed well and remained healed.

In February 1951 a right-sided lumbar sympathectomy was performed for intermittent claudication of the right calf

In September 1951 the second and third toes of the right foot were amputated for gangrene, and then the big toe broke down.

In October 1951 the patient had division of the nerves in the popliteal fossa for his intermittent claudication

In November 1951 a Syme s amputation was performed on the left side This was ill conceived in a patient with vascular disease

The patient remained comfortable until May 1952 when the Syme s stump became painful and blue and he could not sleep He could walk only 40 yards when intermittent claudication set in.

In June 1952, a below knee amputation was performed and equal antero-posterior flaps were made. About 4 in of tibia was left and after main vessels had been tied there was little muscle ooze The patient was fitted with an artificial limb in September 1952.

Early in December 1952, a further series of ulcers appeared on his right foot There was coldness, redness and numbness and early gangrene of the third toe. The first and second toes had been amputated.

The patient was experiencing excruciating pain and on 15 12.52 a below knee amputation was performed, leaving about 4½ in of tibia. The muscle bleeding was satisfactory

On 13 1 53 the stump was well healed and he was measured for his right below knee artificial limb

Both stumps have remained healed and in good condition.

Amputation. With improvement in conservative treatment major amputation is not required as frequently as in the past but it is still performed in about 5 per cent of these patients. It should be avoided if possible and a long period of conservative treatment first be given

A gangrenous toe is better left to slough off spontaneously Amputation of the toe may be resorted to if (*a*) pain is severe (*b*) it is important to save time (*c*) there is no infection (*d*) there is a pulse at the ankle and (*e*) lumbar sympathectomy has been considered and rejected, or has already been carried out

When the pain is very severe and cannot be controlled, and the patient s mental condition is showing signs of strain amputation of the leg is indicated. It is much better for a patient to return to work with an artificial limb than that he should have lost his

morale or become a drug addict or have a leg of doubtful vitality which will probably break down again Amputation of the leg is also indicated when gangrene involves only the foot A below knee amputation is usually better than one through the foot itself and in a youngish person it is also preferable to one through the thigh because an artificial limb is easier to control if the knee remains Even after careful oscillometry it is sometimes extremely difficult to decide whether or not the tissues below the knee have enough blood supply to ensure good healing and often this question can only be answered when the surgeon has made his incision and examined the blood supply of the skin and the cut muscles

With gangrene involving a finger amputation of the finger is sometimes required but loss of a hand is hardly ever necessary

Diabetic Gangrene

Gangrene in the diabetic subject arises in three conditions, all of which are well known as complications of the disease They are of different ætiology and occur in different age groups and therefore we should consider them separately

(1) Primary due to Sepsis The association of diabetes with carbuncles of a particularly virulent type is well known If for example an infective lesion should occur following a paronychia of a toe (usually the big toe) then the lesion progresses rapidly and soon there is infective gangrene of the toe or if left untreated, a spreading gangrene on the dorsum of the foot Degenerative occlusion plays virtually no part in this process It is purely a septic condition This type of lesion is found particularly in the younger group of diabetics or when the disease has been present for only a comparatively short time The treatment will of course be mainly directed towards stabilization of the diabetes and adequate chemotherapy

(2) Secondary to Arterio-sclerosis Arterio-sclerosis is well known to be common in diabetics The longer the disease has been present the more likely the arterio-sclerosis The precise nature of the link between these two diseases is obscure In this group we find the typical senile form of gangrene the foot is often warmer than in the purely arterio-sclerotic and although there may be gangrene of a toe there are often areas of gangrene over the dorsum of the foot as well i e multicentric gangrene The lesion, too tends to be more moist in character probably due to infection facilitated by sugar in the tissues and their consequent devitalization

The treatment here as before will be stabilization of the diabetes and chemotherapy but amputation will be required later The level as will be seen will need to be higher than the actual lesion With care however in the earlier stages the gangrenous part may completely dry up and fall off leaving a good scar One patient even carried a mummified portion of his big toe about with him in a small box

(3) Peripheral Neuritis may be a feature of long-standing diabetes particularly if it is not stabilized because of the occurrence of areas of anæsthesia In such cases ulceration of the anæsthetic areas is often a great problem A combination of anæsthesia and poor blood supply leading to these chronic ulcers may be sufficient to indicate the need for amputation.

Amputation. The decision as to whether or not the early amputation of a gangrenous toe in a diabetic patient should be performed depends upon the degree of infection and the strength of the pulsation in the posterior tibial and the dorsalis pedis arteries at the

(1) ( )

FIG 101 Arteriogram—thrombo-angiitis obliterans.

1 (Right arm.) Circulation of hand being maintained by dorsal interosseous artery Radial artery seen as thin streak. Ulnar artery present in the proximal third only Has " intermittent claudica tion " of forearm.

2. (Left arm.) Ulnar artery sole supply to the hand. Radial artery completely absent, and dorsal interosseous fades out. Note " drum stick " ends on some of the collaterals.

Despite extensive abnormalities, no evidence of gangrene. Plethysmograph studies indicate sur prisingly good blood flow Section confirms diagnosis.

(S Cohen, *Postgraduate Medical Journal.*

FIG 102 Arterio-sclerotic gangrene in a diabetic. Note proximal wedge-like extension. The foot is involved proximal to the metatarsal heads—high amputation (thigh) is therefore necessary
[G y's Hospital Museum.

ankle If the gangrene is infected a radiogram should be taken to establish the extent to which joint or bones are involved If the infection subsides with insulin therapy penicillin and other antibiotics more conservative operations such as transmetatarsal amputations or the local amputations of the toe or toes may prove successful On the other hand it may be necessary to perform a below knee amputation or rarely an above knee amputation

4 Primary Thrombosis of the Popliteal Artery This is found in the young age group mentioned above The patient complains of intermittent claudication of the calf muscles and though hitherto the condition has been diagnosed as Buerger's disease to-day it is found that only the popliteal artery is involved in whole or part of its length Examination of the artery has shown that there is a healthy clot within the vessel and no inflammatory changes of the vessel wall If the patient be generally examined no other evidence of vascular disease will be found. The collateral circulation is good and gangrene does not occur though this is possible much later in life should the patient suffer from arterial disease Furthermore an important point is that the disease does not progress and after many years there is still no further occlusive lesion These cases

Fig 103 Below-knee stump with diabetic gangrene (arterio-sclerosis) Gangrenous patches aggravated by limb-wearing Above-knee amputation.

are believed by Boyd and Wilde to be caused by minor traumata of the popliteal artery as they have shown by their study of the pathology of this vessel

(5) Arterial Embolism Gangrene may result from any one of a number of conditions which may suddenly interrupt the arterial supply to a part of a limb by a mechanical obstruction

Another form of vascular interference that may occur is the sudden occlusion by an embolus This group is a very small part of all cases seen Emboli may arise from the left auricle in auricular fibrillation, auricles and ventricles in congestive failure bacterial endocarditis, atheromatous plaques of the aorta or from fat, air animal parasites, etc which may enter the blood at any site as a result of trauma operative interference with vessels and tissues infections etc

The site of the embolism is usually at the bifurcation of a vessel such as the brachial

Fig 104 Saddle embolus clot at aortic bifurcation. Note distal clot extension. For operation an extra-peritoneal approach through the right common iliac artery is now favoured.

[Guy's Hospital Museum.

femoral or popliteal arteries Having saddled across the bifurcation the embolus may break and travel down each trunk until finally it is arrested The effect of the embolism will depend upon the state of the vessel and lastly upon the occurrence of a propagation thrombus The onset is sudden there is a continuous cramp-like pain well below the level of obstruction accompanied by numbness paraesthesia and paralysis The course of the condition is different from that of pure spasm in that the tissues may slowly die

and gangrene ensue which is by no means typical of pure spasm. Successful treatment again depends on early recognition. Embolectomy if carried out within the first ten hours may save the limb. Even later the combination of embolectomy with attempts to improve the collateral circulation may help to stave off the irreversible changes. These cases, however, are often not seen and diagnosed until the pathological changes are well advanced and gangrene has commenced.

Raynaud's Phenomenon

To complete this account of the causation of gangrene mention must be made of Raynaud's phenomenon. This condition is one of the most important examples of ischæmia following vasospasm. The essential factors are similar to the other conditions described: there is prolonged vasospasm of certain vessels—usually the digital arteries of the fingers and toes which, in advanced cases, may result in gangrene. Why this occurs is a subject under much research. In some cases the condition seems purely idiopathic and in others there seem to be underlying factors. Suffice it to say that the condition is one of prolonged spasm which often leads to gangrene. The signs suggesting the necessity for amputation are: dead white colour with considerable pain, ulceration and gangrene.

Raynaud's phenomenon, according to Lewis, is a local one. Patients have an exaggerated *response to cold, i.e. their blood vessels respond by spasm to cold more so* than in normal people.

During the early stages the local syncope produced by the spasm of the small arteries and capillaries causes them to become relatively empty.

In the later stages of the disease the digital arteries develop an obliterative proliferation of the intima of the vessels and gangrene only occurs when there is organic obliterative changes superimposed on vascular spasm.

3. Traumatic Gangrene

We have dealt so far with the degenerative and infective groups of arterial diseases which comprise the majority of those cases seen clinically. The present group of diseases includes a rather varied collection of clinical types which have one feature in common: they are due to vasomotor changes in the peripheral vessels.

It was John Hunter who first recorded the contraction of the arterial wall in an exposed artery. Since that time many observations have been recorded, both experimental and clinical, of this phenomenon. In studying the literature as a whole, however, one finds only isolated reports up to the period of the First World War during which large numbers of cases were studied and recorded. Similarly in the years between the two wars there was little in the literature compared with the knowledge which accumulated during the recent war. One observation was made many years ago that when a vessel is torn across it quickly contracts. This phenomenon explains why in traumatic amputations of a limb the patient does not always bleed to death. Similar phenomena were later recorded in closed injuries.

Arterial spasm from trauma may arise either from actual rupture of the vessel, or by contusion and irritation of its muscle coats. A penetrating injury may cause the periphery of a limb to become ischæmic and pulseless. This is due either to complete rupture of the vessel or, as is often the case, to injury to the tissues immediately around the vessel. In the former case it is not only the main vessel that is ruptured, but the

collaterals at the same level are also found to be in spasm Similarly in cases that have been explored, it is found that around the vessel there is compression and laceration of the tissue, with a definite segment of the artery in spasm and normal artery above and below Not only is there spasm of that segment but of the collaterals at the same level The cause of this type of lesion is either open or closed injury, actual penetrating wounds causing bruising or fractures where there may be compression of tissues around the artery or, possibly actual irritation by bony fragments Similar ischæmic changes may be caused by a tight plaster Another cause of arterial spasm which should always be in the mind of the orthopædic surgeon is the use of a tourniquet Gangrene due to the application of a tourniquet for long periods, either during a long operative procedure or from failure to remove it at the end of an operation is particularly distressing Burns and particularly electrical burns are prone to cause gangrene under certain conditions The annular full thickness burn of a limb may well cause a scar which slowly contracts As the scar contracts so vessels become overloaded In electrical burns spasm and thrombosis of the vessels invariably result in the loss of part of the limb

FIG 105 Extensive calcification in the soft tissues of the tip of the finger in a case showing Raynaud's phenomenon.

Effects of Cold

Prolonged exposure to cold with continuing spasm of the peripheral vessels will result in gangrene the condition being known as frost-bite Similarly hours or even days of immersion in cold water with limbs hanging down results *in stasis* and prolonged spasm and again gangrene—the latter being termed 'immersion foot The degree of damage in these cases varies It may be loss of skin only or of both skin and deeper structures.

Frost-bite When a limb is subjected to severe cold the first signs of frost bite appear at about 15° C The limb becomes red due to *increase in the amount of oxygen* i.e., there is still oxy hæmoglobin present in the blood because oxygen consumption by the tissue cells has decreased or may have ceased altogether Blood may be still flowing slowly

At 10° C the skin becomes red and loses all sensation, and if muscles are involved

movements become clumsy Below 10 C the vessels are still not completely contracted, and the skin is bright pink and painful At — 2 5° C the tissues freeze and ice crystals form in the tissue fluids At this stage the vessels e g the arteries and arterioles of the frozen part are extensively contracted and the capillaries are dilated The skin and superficial tissues die Necrosis the result of local vascular occlusion occurs during the recovery from frost bite The production of ice crystals does not produce the necrosis

When a patient recovers after being exposed for a short time only there may be no

FIG 106. Bilateral amputation of toes and forefoot following on frost-bite The remaining portions of the feet were saved. Transmetatarsal amputation.

reaction except pain If exposure has been prolonged the skin becomes swollen, the patient complains of local irritation and a burning pain, and the whole limb becomes œdematous and swollen This is first-degree frost bite If exposure has been extreme and the tissues have been frozen and then allowed to thaw the colour of the skin changes to bright red and almost immediately œdema, due to the inflammatory reactions becomes obvious. It is under these conditions that blisters and gangrene occur followed by sloughing of the dead tissues. The development of œdema is slower if recovery is allowed to take place gradually

The Pathology The arteries and arterioles are contracted and the capillaries dilated. The plasma leaks out into the tissues through the capillary walls and the corpuscles

become concentrated and adhere to form a solid mass This is called conglutination These conglutinated corpuscles degenerate and die and the resultant mass causes a thrombosis which produces irreversible local changes in the circulation followed by necrosis

Amputation in Case of Frost-bite

Amputation in these patients should never be hurried It should be remembered that the extent of gangrene in such cases is often much less than the appearance superficially would suggest Distal amputations often prove satisfactory while amputations of the toes and transmetatarsal amputations are commonly successful. In cases of frost bite the pulses are usually palpable in the posterior tibial and dorsalis pedis arteries

Immersion Foot

This condition occurs amongst shipwrecked men whose feet are immersed for a considerable period in water not cold enough to freeze the tissues It may also occur if the feet have been continually cold and wet Tissues freeze at about — 2 5° C and sea water freezes at — 1 9 C so that tissues exposed in unfrozen sea water cannot become frozen. The patients after being subjected to long periods of intense cold possibly on rafts or lifebelts complain that their feet and legs are numb If any sensation is present the patient states that he feels as if he were walking on cotton wool and that he has cramp in his legs The skin changes in colour from red to yellow and this may be followed by changes to blue and finally black. In freezing temperatures at sea the submerged portion of the body becomes a vivid red colour There are two distinct stages —

(a) The Swollen Stage When the patient is taken from the water the hands and feet are swollen and the skin is shiny Anæsthesia of the hands and feet and possibly arms and legs is present so that the patient does not complain of pain

(b) Stage of Diminishing Œdema After a week the hands and feet shrink the skin is no longer shiny but wrinkles form and it becomes pale Anæsthesia passes off except in the distal parts e g the soles of the feet although pins and needles may still continue and prevent sleep Pain may be present at this stage for weeks and the tenderness can be so marked that the patient cannot tolerate the weight of the sheets on his toes

The whole clinical picture bears a resemblance to the condition of peripheral neuritis there being muscular weakness agonizing pains anæsthesia and frequently the loss of reflexes It is noteworthy that the pulses in this case e.g the posterior tibial artery and the dorsalis pedis are easily palpable Gangrene is not an uncommon sequel to this and usually takes place where there has been some pressure e g shoes or boots or where the patient has been hanging on to a rope The condition is a massive chilling and ischæmia of the various tissues of the hand or foot It is therefore clear that the tissues first affected are those most intolerant of injury e g the biologically weakest nervous tissue Connective tissue and tendons survive longest Gangrene in these cases is not a common feature but when it does occur it is usually superficial , massive gangrene however may occur in cases that have been water-logged for about a fortnight Few men however can survive this length of time and in one boat s crew of forty five men only five lived. Of this number the majority had double below knee amputations and some had amputations of the fingers at the metacarpo phalangeal joints or slightly distal

to them The syndrome is therefore in sharp contrast to that of frost-bite in which the superficial tissues become affected by reason of a physical change (ice crystal formation) in the cells of the tissues and the tissue fluids In immersion foot all the tissues become involved simultaneously irrespective of their relative hardihood

The treatment of the disease is not always the same as that for frost-bite In certain circumstances for instance measures for active vasodilatation are indicated in immersion foot but are dangerous in frost bite In the early stages of treatment both types of lesion should be kept cool

Pathology of Immersion Foot and Trench Foot

It has been established that primary degeneration of the nerve fibres is responsible for muscle wasting and degeneration and that an incomplete regeneration of nerve fibres can occur The initial lesion is more widespread than the resulting gangrene suggests so that re amputation of an unhealthy or painful stump is often necessary The earliest tissue changes seen were focal hæmorrhages into the muscles as a result of hyaline necrosis with tearing of the individual fibres Hæmosiderin laden phagocytes remained in the tissues and there was no fibrosis Occasional yellow discoloured areas were noted in the tendons. Thrombosis and intimal fibrosis were found in the veins Obliterative end arteritis was not seen in reported cases of frost-bite so that finding it may be of diagnostic importance After twelve months regeneration of nerve fibres was found in the proximal segment of the limb but complete remyelination of all regenerating fibres was not present after twenty-six months All nerve fibres are not necessarily damaged by the initial trauma but the regenerating axis cylinders return to motor nerve-end plates in the damaged muscle fibres and fail to establish physiological union The bone shows rarefaction and absorption but there is evidence of sub-periosteal new bone formation to restore the radiographic normal contour In these patients blisters form and the skin should be covered with sulphathiazole powder Ointment should be avoided.

The treatment of incipient gangrene has already been described under other conditions In immersion foot and also in trench foot the gangrene is largely superficial and the deeper tissues are not affected. *Trench foot* was common in the First World War and is a type of immersion foot except that instead of having been immersed in brine the limb has been immersed in cold watery mud. In addition to which the men usually wore tight puttees and ankle straps

Sudden Occlusion

(1) Gangrene due to an injury of a vessel, e g popliteal artery from a fracture or dislocation of the upper end of the tibia or brachial artery from a supra-condylar fracture of the humerus

(2) Direct trauma to an artery e g bullet wounds stab wounds or contusion may result in immediate occlusion of blood vessels Injuries of the major vessels occur in war wounds of the extremities more commonly than is realized. The types of vascular injuries noted include contusion with thrombosis lacerated or incised wounds with partial or complete severance of the vessel, and segmental or generalized reflex vasospasm arterial false aneurysm or arterio-venous aneurysm sequelæ to a pulsating hæmatoma.

Vasospasm is a natural response to those forms of trauma which directly or indirectly

affect vascular structures. Accordingly this condition is a common occurrence in most injuries of extremities. Depending upon a number of factors it may involve only a small part of the vessel, may spread to neighbouring vessels of the entire extremity or may be generalized to involve even larger areas of the body. Although it may be considered a compensatory mechanism, under certain conditions if continued it may lead to undesirable and dangerous consequences. In cases in which the actual injury to the tissues has already seriously impaired their vitality, this vasospasm may be the deciding factor upon which the life of the limb depends. An additional consideration is the fact that in

FIG. 107. Volkmann's ischæmic paralysis following on a gun-shot wound of the arm in which the nerves and brachial artery were severed.

some cases the resultant ischæmia may be a contributing factor in the possible development of gas gangrene.

In cases in which there is direct injury to major vessels with laceration, partial or complete severance, or thrombosis, ligation will usually be necessary. The *repair* of these injured vessels in such a way as to maintain blood flow through them is rarely feasible because of the conditions under which they occur and must be handled, and because of the character of the injury. Cleanly incised longitudinal wounds which may be most successfully sutured or even incised transverse wounds which may be repaired by end to end anastomosis or preferably by non-suture tube techniques are only occasionally observed in war injuries. For these reasons the more practical and realistic procedure of ligation must usually be employed. This should be done not by ligation in continuity but by placing non-absorbable ligatures well above and below the site of injury with

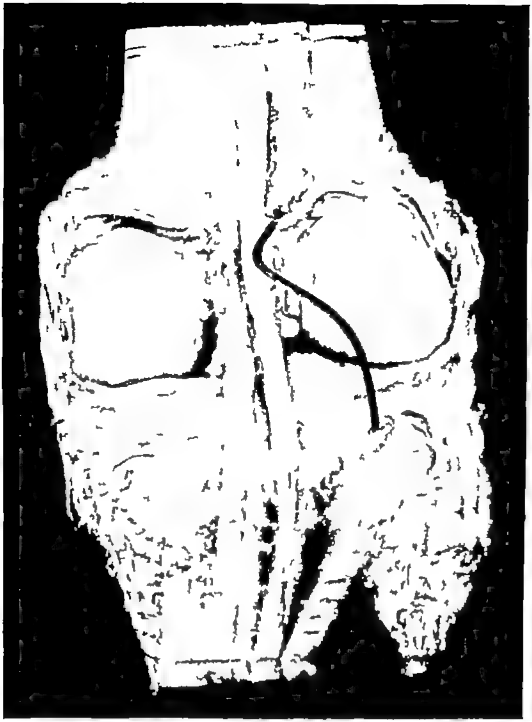

FIG 108 Ruptured popliteal artery (Guy's Hospital Museum) following posterior knee-joint dislocation. Extensive disruption of muscles and collateral vessels usual. Gangrene of leg almost invariably follows. Vein grafting likely to have an important place

[S. M Cohen Postgraduate Medical Journal.

excision of the intervening damaged segment in order to eliminate the dangers of secondary hæmorrhage thrombosis and vaso-constrictor influences The stumps of the proximal and distal segments should then be further secured with transfixion ligatures Other cases with thrombosis should similarly be ligated following excision of the thrombosed segment These cases must be distinguished from localized segmental spasm of

FIG 109 X ray shows mal union. The brachial vessel is often found angulated or trapped between the bone ends.
(S M Cohen Postgraduate Medical Journal.

FIG 110 Segmentary (benign) arterial spasm. Following "near miss" bomb splinter Note bruise distal to hæmostat Collateral circulation not involved in spasm. Radial pulse returned 6½ hours after injury —following local gentle clearing of adjacent loose blood clot
(S M Cohen Postgraduate Medical Journal.

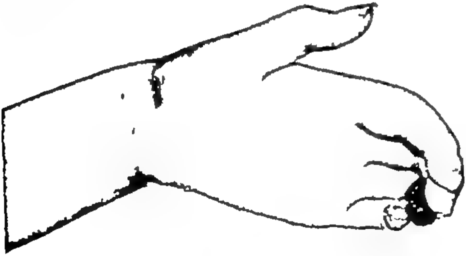

FIG 111 Injury to the brachial plexus with involvement of the brachial artery (Note the gangrene of the tips of the 4th and 5th digits.)

the artery In cases manifesting this phenomenon the limb is cold pale and pulseless but evidence of hæmorrhage or hæmatoma indicating that the vessel has been lacerated may not be present This type of reflex vasospasm is not infrequently noted in cases in which the site of trauma is remote from the vessels In certain cases in which the wound

is immediately adjacent to a vessel which revealed no grossly visible injury the artery has been found in complete spasm Similarly noticeable constriction has been observed following minimal manipulation of a simple fracture The degree and extent of vasospasm vary considerably so that the resulting effect may range from one of slight ischæmia to a more generalized involvement especially of the collateral circulation, with sufficient ischæmia to produce actual gangrene Moreover the vasospasm may persist for periods as long as or even longer than forty-eight to seventy two hours

Rational treatment in these cases is directed towards counteracting vasospasm and producing maximum vasodilatation in the involved extremity Since the disturbance is apparently due to the development of a vasomotor reflex initiated in the traumatized tissues and since vasoconstrictor impulses are transmitted by way of the sympathetic

FIG 112. Type of fracture often followed by extensive reflex arterial spasm No direct vascular trauma, no bone displacement—but much local tissue insult
(S. M. Cohen *Postgraduate Medical Journal.*

nerve fibres interruption of these impulses in the circuit prevents vasospasm and permits vasodilatation This interruption may be accomplished by débridement of surrounding traumatized tissue peri arterial sympathectomy or procaine hydrochloride block of the regional sympathetic ganglia. The last procedure is considered the most effective method of producing maximum vasodilatation in these cases and should be employed in all types of peripheral vascular injuries accompanied by manifestations of vasospasm It may be necessary to repeat the sympathetic block at least once or twice daily for several days There may be veno-spasm in addition to arterial spasm and this comes on at the same time as the arterial spasm Amputation is however seldom necessary as sympathectomy is usually successful in preventing this

It is not generally agreed however (see Learmonth) that sympathectomy will relieve arterial spasm due to trauma and it is certain that peri-arterial sympathectomy may do more harm than good.

Removal of the traumatizing agent is usually satisfactory. In the recent fighting in Korea large defects in major vessels have been bridged by homografts stored in nutrient media or dry ice. The most satisfactory graft to date has been the lyophilized or freeze-dried graft as developed in the U.S. Navy Research Centre at Bethesda.

War experience, however, has revealed in the past that when main arteries are

FIG. 113. Below knee amputation. Sinus on anterior aspect of stump marked by metal ring. The amputation was necessitated by a vascular accident. It will be seen that there is increased density of the remaining portion of the tibia. The bone is dead and later amputation at a higher level was found necessary.

shot away the concomitant soft tissue or major nerve loss means a useless limb even if it does survive. Close observation is essential in major peripheral vascular injuries. Proper positioning of the extremity is of importance as elevation may accentuate the ischæmia. Operative procedures for arterial or arterio-venous aneurysms are best delayed.

(3) A vessel may be ligated for the treatment of an aneurysm or an error in surgery may result from ligature of a main blood vessel, e.g. femoral artery for saphenous vein

FIG. 114.—Volkmann's contracture. Characteristic deformity. Hyper-extension of the metacarpo-phalangeal joints, and finger flexion. The fingers extend on flexing the wrist.

[S. M. Cohen, *Postgraduate Medical Journal*.

FIG. 115.—Volkmann's contracture (× 30). Islands of muscle in "sea" of fibrous tissue. Dead muscle fibres are being replaced by scar tissue. The active replacing edge can be seen.

[S. M. Cohen, *Postgraduate Medical Journal*.

(4) Gangrene from an incorrectly applied plaster or splint to a limb or a forgotten tourniquet

Maintained Occlusion

Fractures tight plasters injuries of joints and soft tissues are always accompanied by œdema to a greater or lesser degree It is unwise to envelope them in circumferential skin tight plasters or even bandages before the reactive swelling has been allowed to

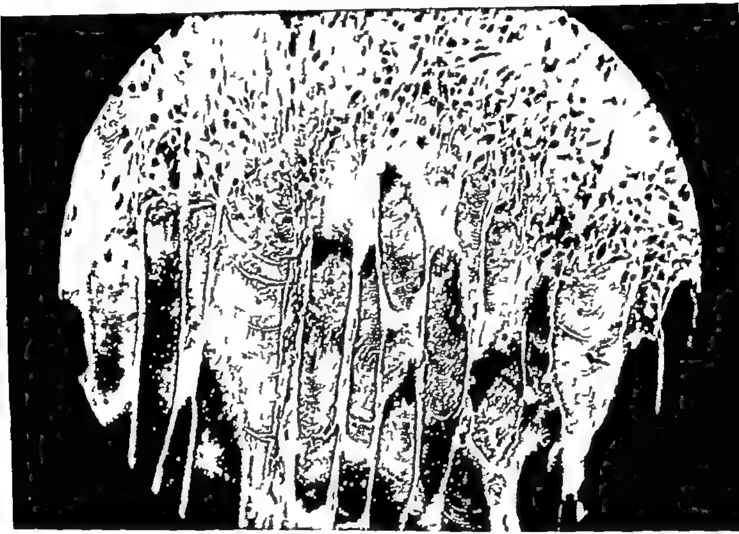

FIG 116 Volkmann's contracture. High power view of replacing edge Shows active cellular layer "biting" into and engulfing muscle fibres. Note complete absence of muscle nuclei Striations are retained. Fissuring of fibres is evident

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settle down It should be a cardinal principle that the œdema should be treated *pari passu* with the reduction of the fracture for it is the œdema together with any circumferential compression which may lead to lymphatic venous and arterial obstruction followed by Volkmann's contracture or gangrene

A tourniquet may unfortunately be left in position after an operation and the patient returned to the ward This would not occur if the precaution is taken to tie the end of the tourniquet to the operating table When this accident takes place and if the tourniquet has been left on for six hours and then released the patient suffers severe shock

FIG. 117. Skin tight plaster with gangrene of the first and second toes.

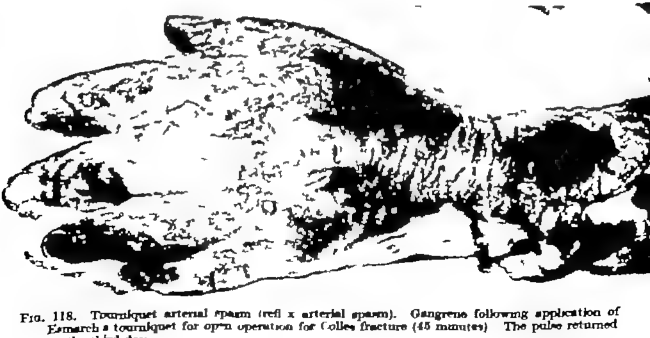

FIG. 118. Tourniquet arterial spasm (reflex arterial spasm). Gangrene following application of Esmarch's tourniquet for open operation for Colles fracture (45 minutes). The pulse returned on the third day.

[S. M. Cohen, *Postgraduate Medical Journal*.

and usually dies as a result of uræmic symptoms The surgeon is faced with a terrible decision as to whether to attempt to treat the uræmia which inevitably occurs after release of the tourniquet or to leave the tourniquet in position return the patient to the operating theatre and amputate the limb above the site where the tourniquet remains Fatal uræmia is the primary danger but gangrene will ensue if the patient were to recover

Amputations are best undertaken in such cases of vascular obstruction at the levels set out below The levels here advocated are those most likely to result in a well

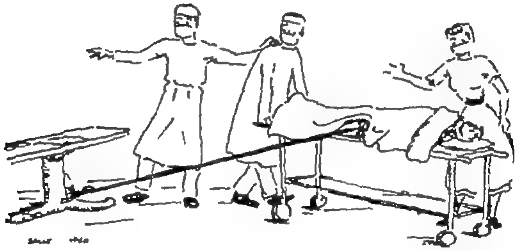

FIG 119 Tourniquet tied to the operating table The catastrophe of failure of removal can be avoided.

(J Ive, Brit. J Anæsthesia.

healed stump which has useful function Occasionally one may succeed in amputating a limb successfully at a lower level than that which is advocated

It should, however be remembered that the vascularity of the skin is not a true reflection of the state of the underlying muscle and bone One has seen cases where the vascularity of the skin at a particular level seemed satisfactory yet the underlying muscle and bone had undergone necrosis were of no value and prevented healing

In recommending these sites it should always be borne in mind that (1) healing will depend on the state of the vessels in the remaining part of the stump (2) it is important to take into consideration whether the block has been sudden or gradual and (3) the anatomical arrangement of the collateral circulation is not always a true indication as to what is likely to follow

All cases of high femoral interruption should be nursed if possible face downwards to open up the collateral circulation in the gluteal region while all cases of subclavian and axillary interruption should be nursed if possible on the unaffected side so that there is no pressure on the scapular collateral circulation This applies both pre-operatively and post-operatively

Levels of Amputation

Upper Extremity (1) *Subclavian Artery* An amputation of the arm through the middle of the humerus is the usual site although with a subclavian thrombosis only a finger or two may be lost

FIG 117 Skin tight plaster with gangrene of the first and second toes.

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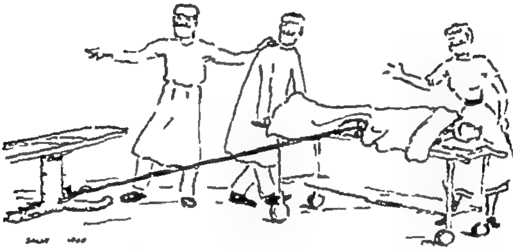

FIG. 119. Tourniquet tied to the operating table. The catastrophe of failure of removal can be avoided.

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(2) *Axillary Artery* One may not require an amputation at all although the tips of the fingers may become gangrenous

(3) *Brachial Artery* There is usually no gangrene but Volkmann s ischaemic paralysis may occur

Lower Extremity (1) A block in the lower end of the aorta or in the iliac vessels which results in gangrene will require an amputation above the knee and usually at a high level—6 to 8 in (15 to 20 cm.) from the greater trochanter

(2) A block of the femoral artery above the profunda femoris requires an amputation above the knee The length of the stump should be eight or nine inches Below the profunda femoris a below knee amputation rarely proves satisfactory

(3) A block of the popliteal artery—a below knee amputation usually proves success ful (never a Syme s amputation)

General Principles in the Treatment of Arterial Obstruction

The surgical treatment of incipient or established gangrene can be (1) conservative in the hope of saving as much of the limb as can be induced to heal, thus circumventing major operative procedures so that the necessity of an artificial limb does not arise and (2) operative when gangrene is already established. The treatment then consists of either conservative or radical surgery

Amputation often becomes necessary in the treatment of peripheral arteriosclerosis, but conservative treatment should always be first considered In patients with moderately severe pain, and when gangrene is limited to the toes the choice between further con servative treatment and amputation often depends as much on economic consideration as on medical ones The general health etc of the patient is usually the deciding factor when amputation for this condition is considered. Such apparently minor disturbances as lack of sleep etc should be taken into account

The patient s occupation and economic and social position must play a large part in the decision When only a moderate degree of arteriosclerosis is present it is advisable to delay any decision for a few weeks When a whole toe is gangrenous it is usually better to allow it to slough spontaneously rather than to amputate though a local amputation through the metatarso phalangeal joint may be useful occasionally when the line of demarcation is sharp and the blood supply is good at the base of the toe or when as is not uncommon a phalanx is fractured

A case is known in which a patient a prisoner of war in Japan, lost all the toes on both feet by gangrene A perfectly healthy scar formed across the heads of the meta tarsals The only treatment was given by the patient himself He just washed the gangrenous tissue away as it formed

In more extensive diseases, with a gangrenous foot or leg and when pain is uncon trollable early amputation of the leg is indicated, and it may be a life-saving measure It is well to remember that in arteriosclerosis the mortality from amputation of a leg is 4 to 8 per cent usually due to post-operative vascular accidents elsewhere in the body With diabetes mellitus it is higher still, owing to the increased risk of spreading infection.

Many surgeons believe that amputation of the leg in arteriosclerosis is best when carried out above the knee at the junction of the middle and lower thirds of the thigh because they consider that the better chance of healing at this level, and the smaller chance of infection outweigh the advantages of a below knee amputation in the fitting

and wearing of an artificial limb Elderly persons however do not take easily to artificial limbs of any kind

1 Conservative Treatment In the treatment of incipient gangrene it is essential that the patient should be confined to bed He should not be allowed to go even to the bathroom It may be of assistance to raise the head of the bed on blocks Analgesics are often necessary Small superficial areas of gangrene should be kept dry and aseptic by dusting with suitable powder or by pouring surgical spirit on a light gauze dressing and allowing it to evaporate This cools the affected part keeps the surface aseptic and dries the gangrene If possible the foot should be exposed to the air but protected by cradles from pressure both day and night—always aim at cooling off the part Nurses should be forbidden to provide the patient with hot water bottles as it is inadvisable in view of the fact that the circulation is already at its maximum and there is gangrene from its insufficiency By raising the temperature and consequently the metabolism without being able to increase the circulation of blood there is no reserve in the circulation to cope with increased demands thus the condition will be made worse Heat however may be applied to the unaffected leg and foot so that reflex dilatation of the vessels in the affected foot may increase the quantity of blood in circulation There is no rise in temperature no great increase in tissue metabolism and vessels have a maximal dilatation (see Learmonth 1943) The superficial dry gangrenous areas should be allowed to separate as they often do leaving a granulating and comparatively healthy surface with the eventual formation of a healthy scar

2 Conservative Surgery This consists of draining any abscess which may surround and underlie a gangrenous patch particularly when diabetes is present If the gangrene is deeper and involves more than the superficial skin it is usually found that the whole thickness of the limb has been devitalized This is a serious form of gangrene more especially if it has become infected As a first line of treatment in this condition wound toilet should be undertaken under general anaesthesia and the whole gangrenous area extirpated leaving the depths of the wound open to drain It will be found that the toxaemia and therefore the general health of the patient improves so rapidly after this that a more favourable operative proceeding can be anticipated Appropriate systemic antibiotic therapy and chemotherapy should at the same time be prescribed

Areas of Gangrene involving a Digit. Unless the patient is toxic and the gangrene is spreading one should wait until a line of demarcation has appeared

A radiograph will probably show whether the underlying bone or joint has become involved but this is not always so Amputation should be undertaken at a little distance above the line of demarcation and if possible the wound should be lightly sutured, without tension with one or two sutures The big toe and fifth toe heal badly owing to the poor collateral circulation The middle toes heal more rapidly Patients suffering from these conditions frequently complain of severe pain which may be associated with oedema or cellulitis when the gangrene spreads

Massive Gangrene Under this heading is included gangrene which not only involves the toes but has already involved the foot Here a major amputation will have to be undertaken and the site will depend upon the nature of the disease and the ability to control the infection with antibiotics Further it will depend upon the oscillometer readings over the limb before the operation while at the time of the operation the degree of bleeding which takes place may influence the ultimate decision on the level and should be

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assessed not only from the skin vessels, but also from the cut muscles *Operations for gangrene should not be performed under a tourniquet* The problems are discussed in detail in Chapter II

Treatment of a Patient with Gangrene

A man usually past middle age attends with a painful foot Examination reveals a black gangrenous toe and the foot shows a persistent redness Pulsation in the vessels is no longer palpable Examination of the man as a whole is revealing His expression is often one of hopelessness derived from many sleepless nights already with an inkling of the fact that this toe will never recover and that he will probably have to lose part of his limb The ischæmic pain will have affected him for many months His appetite for food will long since have gone The combination of his anorexia and the condition of his foot will have caused loss of weight and nutritional anæmia We have therefore a man who has not only lost the circulation to his limb lost weight and probably his job but what is worse has lost his morale Never was the old aphorism of medicine more true ' treat the patient and not the disease '

General Treatment

The patient must be put to bed and have first-class nursing Suitable analgesics should be administered during the day and also later to ensure a good night s sleep This alone will result in some improvement

The poor nutritional state with the lowering of plasma proteins and anæmia, must be corrected Elderly people have often been living upon an ill balanced diet The patient must therefore be gradually placed upon a full mixed diet with adequate proteins His anæmia should be treated with doses of iron or if the hæmoglobin is very low by

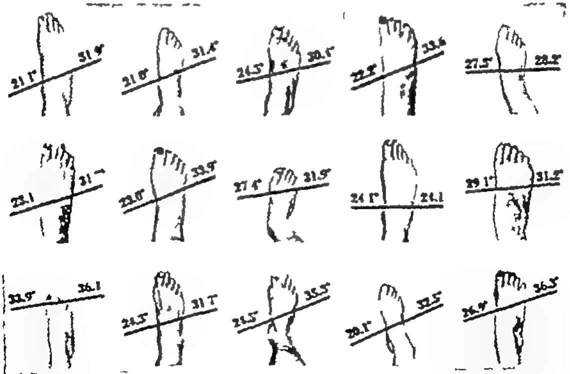

FIG 120 Rise in skin temperature of toes in 15 patients after a single administration of Priscol.
(*This illustration is based on the work of W J Reedy J Lab. clin. Med., 1951 37 903. Reproduced by courtesy of CIba Laboratories Ltd*

giving him a blood transfusion as well preferably *fresh blood* Extra vitamins should be added to the diet Here we may mention the use of vitamin E or α tocopherol The effect of the latter upon the circulation is not definitely known Some authors (Bicknell and Prescott The Vitamins in Medicine) claim that it is of help in cases of claudication and while it will do no harm its administration may help the peripheral circulation to some extent

Drugs such as Priscol are helpful and although they cannot possibly influence the fate of the part they may improve the circulation of the rest of the limb making the healing after operative procedure quicker

These are the general measures recommended *They are of the greatest importance* The patient s outlook towards his condition will have changed remarkably after rest absence of pain and correction of his poor nutrition

Summary of Treatment. One of the most important features of the acute ischæmia here emphasized is persistent pain when at rest Experience has shown that if rest pain has been present for six weeks or over a major amputation is inevitable Furthermore the longer rest pain is allowed to persist the more trouble is experienced later with the phantom limb The conservative regime we adopt consists of —

CENTRAL

(1) Bed rest
(2) Head of bed on 5 in blocks unless there is any peripheral œdema—when the patient is nursed flat
(3) Suitable and heavy analgesia
(4) The body is kept warm—the best method of producing peripheral vaso dilatation
(5) The affected limb is kept cool—to a temperature of about 70 F This should be *especially watched in the winter—and a thermometer should* be present in the cradle
(6) Vasodilator drugs such as Priscol Hydergine dihydroergotamine Cyclo spasmol may be used
(7) Tocopherol in large doses may be used for its long term effect but not as a vasodilator
(8) Attention is paid to dehydration cardiac irregularity anæmia vitamin deficiency etc

Local Treatment

Non-operative While in bed the limb of the patient should *not* be elevated It is possible clinically to see the blanching effect of this for prolonged raising of the limb results in further reduction of the already deficient circulation It is often advantageous on the contrary to raise the head of the bed by 5 in thus ensuring a constant favourable circulation to the lower limb

The patient often complains that his feet are cold but evaporation of fluid from the tissues in the treatment of gangrene should be encouraged by exposure of the part to air The foot is best kept comfortable by the use of woollen bed socks

The next problem is that of the hard black scab If it is clean and dry it should be kept like this by *powdering with penicillin powder* Pus on the other hand may be form ing beneath this black dead tissue and instead of coming to the surface and draining

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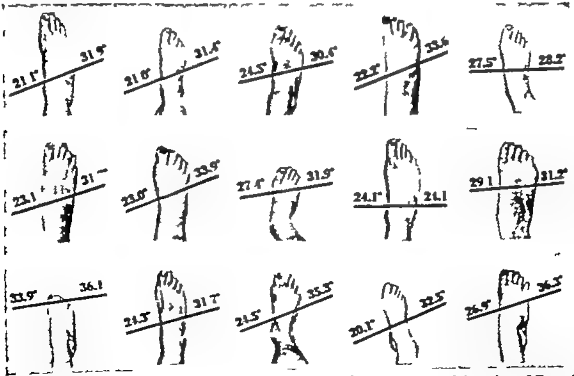

FIG 120. Rise in skin temperature of toes in 15 patients after a single administration of Priscol.
[*This illustration is based on the work of W J Reedy J Lab. clin. Med., 1951, 37 365. Reproduced by courtesy of Ciba Laboratories Ltd.*

has found that the younger the patient and the shorter the history of diabetes the better the result It is with the patient who has had pure infective gangrene which has been controlled with chemotherapy and stabilization of his diabetes and who has only a small residual gangrenous part that this operation is successful The functional result after operation is very good the gait is almost normal However over 15 per cent of these cases required re amputation and in the majority, the operation is contra indicated by œdema etc over the whole dorsum of the foot Operation must not of course be attempted until sepsis has been completely controlled Lisfranc s and Chopart s amputations are unsuitable in these cases

(iii) *Above or Below-knee Amputation* These are the usual procedures but the question arises which should be performed ? It is wrong to carry out an above knee

R L

Fig 121 Bilateral above knee amputation. Extensive arterial calcification. Large ring sequestrum present at lower end of the left femur

amputation when a below knee would suffice and similarly it is most undesirable to have to re amputate for non healing of a below knee stump The end result must provide a stump that is painless well healed and fit for limb wearing An unsatisfactory stump may occur in both below knee and above knee amputations The reasons for failure are related directly to the blood supply Pain that occurs is often of the claudication type due to inadequate blood supply to the musculature The skin may show various changes such as œdema cyanosis become thin and atrophic or may have actual ulceration The ætiology of this ischæmia may be either complete obliteration of the main vessel to the stump or spasm—the latter in either of the main vessels or the collaterals René Leriche has shown by arteriographic study and sympathectomy that spasm plays an important role in the pathology of these lesions

It is desirable to perform a below knee amputation whenever possible particularly

may become imprisoned. Its retention may cause damage deep in the tissues If therefore pus is present it should be evacuated and the scab treated with Eusol or surgical spirit dressings If there is already infection present and just before any operative measures a course of penicillin should be instituted In the diabetic patient the diabetes must be carefully stabilized. This alone may result in marked improvement of the condition.

Operative Treatment. In vascular diseases amputation needs care and detailed consideration. In a study of the literature one finds descriptions of various methods recommended for gangrene Amputation is not without risk in the elderly patient and one must therefore carry out the operation, if possible so that the flaps will have an adequate blood supply and thus eliminate the necessity for re-amputation at a higher level On the other hand, one does not wish to remove more of a person s limb than the *condition requires It is the level at which the operation should be carried out that is* the main subject for discussion.

1 Amputation through the Line of Demarcation of the Gangrene This is *the minimum that can be attempted A racket incision should not be used for digits as* the digital vessels may be injured with consequent gangrene The digit should be amputated through the line of demarcation with the bone proximal to this line being nibbled out until the next joint is reached The cartilage is then removed from the phalangeal or metatarsal head thus exposed and the cuff of skin either packed with paraffined gauze or loosely approximated with a stitch. In the frail very elderly patient whose expectation of life is short the risk of a major amputation is contra indicated The removal of the gangrenous part as described often leaves a painless stump which soon granulates and heals fairly well.

2 Formal Amputation The patient naturally objects to the decision of the surgeon to carry out an above-knee amputation when he is only suffering from gangrene of the toes Similarly the surgeon is often tempted to lower his site of amputation First consider the types of operation that may be performed.

Absolute indications for early amputation are considered to be —

(1) Gangrene anywhere peripherally with absent oscillations below the knee

(2) Gangrene of first or fifth toes of the heel and of the dorsum of the foot even if there is a slight oscillation below the knee

It is usually impossible to avoid major amputation at these sites unless there are reasonable oscillations at the ankle

(i) *At Metatarso-phalangeal Joint*—by using the usual racket incision. The length of the incision is extended into the plantar aspect *deliberately ignoring the fact that* the scar may be painful, because there is a considerable risk of the wound breaking down and in such a case with a plantar wound there will be dependent drainage Often merely amputating the digit will be successful but it should be carried out only if the gangrene is well localized or if there has been a successful sympathectomy or therapeutic para vertebral block If however anaesthesia or oedema of the foot is present this procedure is invariably doomed to failure

(ii) *Trans metatarsal Amputation* This form of operation is recommended particularly by McKittrick, who has practised it principally in diabetic gangrene His reasons for advocating this procedure are (*a*) there may be gangrene of one or more toes that does *not* extend to the dorsal or plantar aspect and (*b*) any infection is controlled He

found in some cases and thus is an indication for an above knee amputation When there is definite redness of the dependent foot and blanching when the part is raised extending well into the leg with a slow return then the fate of the below knee stump is in doubt Palpation of the popliteal is difficult sometimes but its absence must remain a point against the below knee amputation

FIG 1 3 Lateral view of an arteriogram of an amputated below knee stump The vessels are well outlined. Note that there is a continuous subcutaneous arcade but very few vessels reach the skin Unable to wear a limb because of intermittent claudication.

(b) *Reactive Hyperæmia (Lewis)* The limb must be warm for this test A cuff placed around the thigh is inflated above the systolic blood pressure and retained there for at least five minutes The hyperæmic flush that occurs within 5 seconds after release is mapped out and gives some indication of the vascularity of the part

(c) *Oscillometry* Absence of pulsation above or immediately below the knee is of course a contra indication to the below knee type of operation

The above methods may demonstrate a block of a main vessel and to a lesser degree give an indication of the collateral circulation

(d) *Arteriography* may be employed to give a much better pre-operative conception

if there has already been an above knee amputation on the other leg and also when there is marked arterial disease of the other limb. The aim must be to choose the site of election and then amputate so as to get sound healing and a satisfactory stump. Many authors have enumerated the criteria to be adopted in cases when a choice has to be made between a below- or above-knee amputation. It cannot be emphasized too strongly

Fig 122 Antero-posterior view of an arteriogram in an amputated below knee stump. The arterial tree has been well outlined. The main vessels are the collateral ones. Note the main vessels end abruptly. Unable to wear a limb because of intermittent claudication.

that it is extremely important to assess the condition of the circulation before operation. It will depend upon this assessment which operation is performed.

(a) *Clinical Observations*. The temperature of the part should be measured. A definite change in temperature at a level above or immediately below the knee may be

was able to restore the patient to his former activity before the development of the disease (2) in the more severe cases whether a sympathectomy had any value in limiting the amputation and (3) whether sympathectomy was of value in preventing the further progress of the disease They have shown that peripheral vascular disease and other allied conditions are affected by sympathectomy

Although there is no doubt that sympathectomy will improve blood supply to a degree I have rarely found that what would have been a thigh amputation has been converted into a below knee amputation by sympathectomy This was borne out by an unpublished series of Fitzgerald in Dublin

On the other hand sympathectomy has been more successful with the more peripheral types of vascular occlusion and often succeeds in limiting gangrene to a toe

Chemical sympathectomy by paravertebral block with 10 cc of 10 per cent phenol is often successful in cases who are too ill or too old for lumbar sympathectomy

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of the vascular supply This procedure however involves many technical difficulties the interpretation of the film being difficult except to those familiar with this form of investigation

(e) *At Operation* This is the final criterion A tourniquet should not be applied as there may be vascular spasm which will tend to mask the picture The appearance of the muscle and skin edge will give the final answer Even when fashioning a long above-knee stump these points must be borne in mind, for often there may develop ischæmic pathological troubles With the below knee amputation where the collateral circulation is adequate the area which it has to supply should not be too great The stump should be kept short—about 4 in (10 cm) of tibia is satisfactory

Major Amputations The mid thigh amputation should not have dissected flaps. Equal antero-posterior flaps should be cut taking skin, subcutaneous tissue and muscle down to the bone so that the nutrition of the skin and subcutaneous tissue is not impaired by cutting across the collaterals coming from the muscle The 9 in. stump is used No drainage is permitted as primary healing is important Bandaging should not be too tight and dressings should be changed on the fifth post-operative day (unless inspection is indicated before by complaint of tightness in the stump) so that hardened gauze should not be left too long in contact with the suture line Pressure necrosis may quite easily occur under these circumstances

The aim should be (*a*) to help and improve any deficient circulation in the remaining limb and also (*b*) to guard carefully against any of the lesions that may lead to infection and so precipitate gangrene

Finally there is the question of sympathectomy or other treatment to improve the peripheral blood supply in relation to amputation surgery These operations are based on the principle that removal of the adventitia over an area of at least an inch of the main vessel to a limb will remove the sympathetic (vaso-constrictor) nerves to a limb and thus vaso-dilatation will result The operation was devised in 1899 by Jaboulay and subsequently extensively performed by Leriche

The basis of the modern treatment of peripheral vascular disease began in 1924 when Royle showed that skin changes such as coldness and sweating of the extremities could be improved by regional sympathectomy

In 1925 Adson and Brown were able to demonstrate by means of calorimetry on the skin of the extremities that vasospasm could be relieved by periarterial sympathectomy and ganglionectomy

It is known that sympathectomy will not always relieve deficient circulation such as intermittent claudication but this measure may result in considerable relief from rest pain on the other hand the circulation to the skin itself may also be greatly enhanced Some idea of the possible benefit may be indicated by sympathetic inhibition (sympathetic block) if the response to this test is good then the operation may well be worth while (See Chapter XII for further details) If the patient s general condition excludes the possibility of sympathectomy then Priscol should be administered The effect of administering this drug may not be great but it may be sufficient to stave off actual ulceration

Recently Hendrick and Guy have reviewed their results of sympathectomy for peripheral vascular disease and have evaluated 198 cases with a fifteen year follow up

They followed up their cases with a view to showing (1) whether sympathectomy

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as well as physical pain and insecurity. The surgeon should know what to do for a child and what a child amputee with a well fitting prosthesis can do. Nature has endowed the child with the instinct to walk. The child with a deformed or absent limb is intent on walking, despite its physical handicaps.

Children are often unkind to their playmates with abnormal physical conditions. This not only causes the afflicted child a great deal of unnecessary mental pain, but it

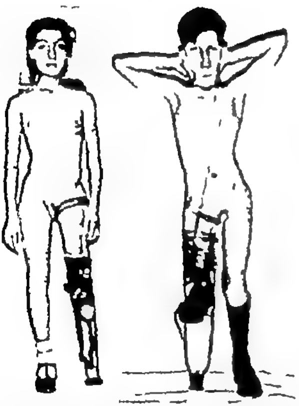

Fig. 125. Short limbs due to congenital abnormalities and wearing splints. Both these deformities can be corrected within artificial limbs with a good functional and cosmetic result.

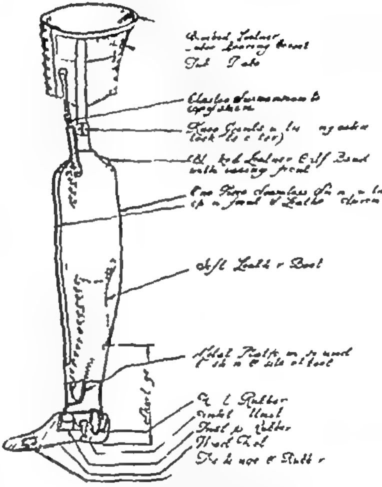

Fig. 126. Extension limb: showing the general principles involved in concealing a short deformed limb. This can be modified according to the particular deformity.

may be the starting point of a psychological complex which reacts to his detriment at a later age.

Congenital Abnormalities. Shortening of about ½ in. in the lower extremity rarely gives rise to symptoms or requires treatment. Occasionally there is congenital shortening of considerable degree in one of the lower limbs, which makes walking difficult and produces an ungainly limp and a secondary scoliosis.

If this shortening does not exceed 3¼ in. (8 cm.) in a child it may be corrected by epiphyseal arrest on the sound side, or in the older patient by a femoral shaft shortening. Although there are methods of lengthening the leg, post-operative complications may make it a hazardous undertaking.

CHAPTER VII

DEVELOPMENTAL ANOMALIES OF LONG BONES REQUIRING ARTIFICIAL LIMBS

"The feasibility of an operation is not always the best indication for its performance"

HENRY COHEN

Annals of the Royal College of Surgeons of England

A surgeon who intends to amputate a limb should never hesitate to get a second or even a third opinion before committing himself.

A surgeon who amputates because of the severity of the local injury assumes a grave responsibility—particularly in the case of the upper extremity—and a second opinion should always be sought before proceeding to this drastic step.

Medical Research Council War Memorandum No 5 1941

AMPUTATIONS in children have a more distressing effect on the mind of the surgeon than amputations in adults yet they may be necessary in order to save the child mental

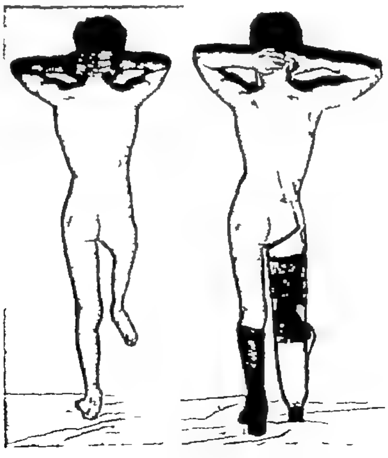

FIG 124. Congenital short limb involving femur tibia and fibula. Foot in equinus. Splint is unsightly A suitable case for an extension limb. Note scoliosis.

as well as physical pain and insecurity. The surgeon should know what to do for a child and what a child amputee with a well fitting prosthesis can do. Nature has endowed the child with the instinct to walk. The child with a deformed or absent limb is intent on walking despite its physical handicaps.

Children are often unkind to their playmates with abnormal physical conditions. This not only causes the afflicted child a great deal of unnecessary mental pain but it

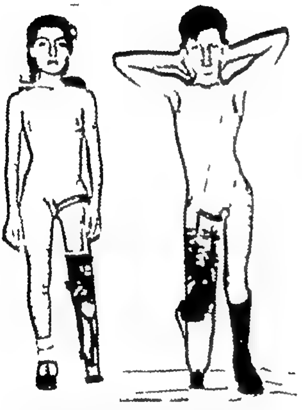

FIG 139. Short limbs due to congenital abnormalities, and wearing splints. Both these deformities can be corrected within artificial limbs with a good functional and cosmetic result.

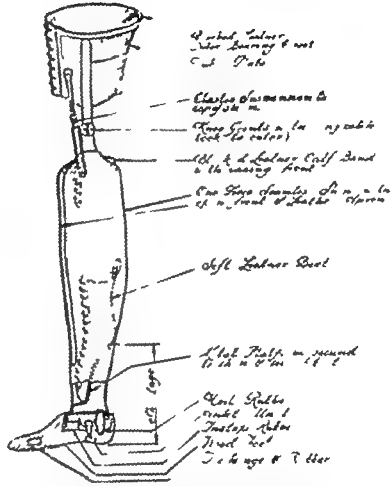

FIG 140. Extension limb; showing the general principles involved in concealing a short deformed limb. This can be modified according to the particular deformity.

may be the starting point of a psychological complex which reacts to his detriment at a later age.

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Acquired Abnormalities. A great number of limb irregularities fall into this group Shortening may occur in —

(1) Infantile paralysis

(2) Patients with tuberculosis of joints or osteomyelitis may have either increased or retarded bone growth, according to the way it affects the epiphysis

To delay too long with an incurable disease or a deformity which fails to yield to orthopaedic treatment is to condemn the child unnecessarily to a long period of inactivity during the most vital years of his growing period. The surgeon, therefore must have a knowledge of the diseases and congenital deformities which may necessitate an amputation and of the amputations best suited to the child's limb having regard to the times of epiphyseal fusion

The indications for amputation do not differ greatly from those in adults These have already been discussed A few additional points concerning the management of such cases are included in this chapter The number of combinations of congenital anomalies of the long bones that present for advice and treatment makes it essential to include a section on this subject in this book. For the successful understanding and management of these cases a knowledge of the development of the normal limbs is necessary as well as of interest While errors of development are complex, a simple classification is essential to the surgeon and to the limb fitter

Development of the Skeleton of the Extremities

Strictly speaking congenital absence of limbs or segments of limbs is an example of agenesis From the limb fitting point of view the bones which concern us are the long bones which are developed in cartilage

The skeletal core of the future limb is produced by a bud of vascular mesenchyme which is condensed in the axis of the developing limb The skeletal blastema or core becomes still further condensed in the situation of the future bones and distally into the hand or foot-plate This stage is called the prechondral stage The prechondrium is then converted into cartilage by the appearance of a centre of chondrification During the chondrogenetic stage the limbs acquire the many features of the adult form The joints are at first represented by remaining areas of mesenchymatous condensation between the cartilages By the end of the fourth month the joint cavities have appeared and the surrounding mesenchyme is condensed and thickened into capsular ligaments Intra articular structures are derived from primary blastema Centres of ossification next appear in the cartilage and correspond to the preceding centres of chondrification

The cartilage tissue is transformed into bone by the activity of specially modified mesenchymal cells known as osteoblasts

There is an intermediate deposition of cartilage which acts as a temporary framework and is ultimately replaced by true bone The long bone is at one stage a homogeneous cartilaginous structure which can grow in any direction except where it is invested with a thickening of embryonic connective tissue which tends to regulate its shape This investing layer is the perichondrium which later gives rise to the periosteum

At certain chronological stages centres of ossification appear in the diaphysis and at either epiphysis of the long bones From these centres the process of ossification spreads outwards At the periphery bone is laid down along the whole length of the shaft beneath the layer of periosteum

Ultimately the whole of the bone and its two ends become completely ossified except for an area of cartilaginous cells which separates the shaft from either end. This area is known as the epiphyseal plate. Growth in length takes place at both ends of a long bone by proliferation of these cartilage cells at the epiphyseal line. The active epiphysis for longitudinal growth in the femur is at its distal end. In the leg the active epiphyses for growth of the tibia and fibula are at their proximal ends. The skeleton portion of

Fig 187 Congenital deformity of lower limb which consists of an amorphous bone fragment representing a femur and two rudimentary phalanges, an example of agenesis.

Fig 188 Congenital absence of the fingers with ... mentary fingers attached to the palm pad.

the stump increases in length proportionally more in the leg than in the thigh. In the upper extremity the most active growth occurs at the head of the humerus while in the forearm the actively growing epiphyses are at the carpal ends of the bones. About the age of sixteen to twenty the epiphyseal plate itself is replaced by bone and the epiphysis is then joined to the diaphysis; further increase in length usually ceases at an earlier date.

Transformation of the Limb-bud. During the prechondral stage important alterations are occurring in the form of the limb bud —

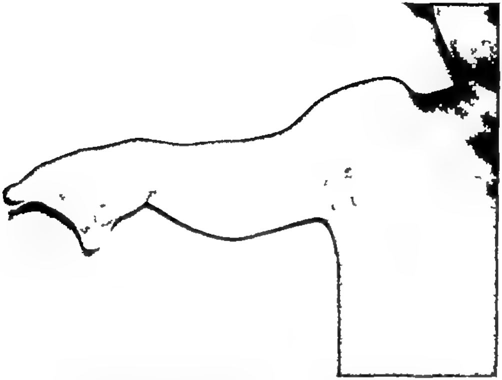

Fig 129 Congenital malformation of upper extremity involving elbow forearm and hand with webbing of the fingers, the thumb and 5th finger being the only digits which have appeared. Failure of angulation, elongation and digit formation.

Fig 130 Radiograph of Fig 129 Congenital deformity of arm with fusion of humerus, radius and rudimentary ulna. Only two deformed fingers are present. The remainder are represented by scattered bone remnants.

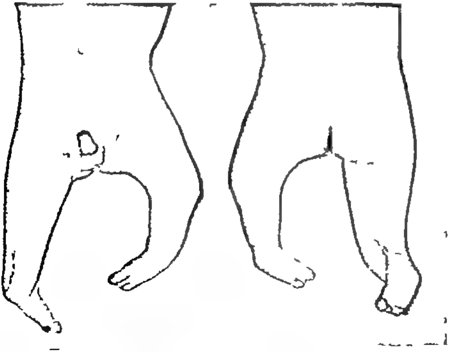

Fig 131 Bilateral maldevelopment of both lower extremities. A combination of failure of elongation, angulation and rotation. Excision of the left knee-joint was required before a suitable prosthesis could be fitted.

(1) The fœtal limb bud consists of a root segment which is nearest to the trunk and which differentiates into the humerus or femur an intermediate segment which divides into two longitudinal parts and which differentiate into the bones of the forearm or leg and a terminal segment in which four notches appear in order to separate the five primitive digits

(2) ELONGATION of the limb bud now occurs by internal and peripheral growth so that it is directed downwards and outwards from the trunk

(3) ANGULATION is next to be noted As the limb elongates three angles are formed in it by the establishment of joints between the four main elements of the limb—at the

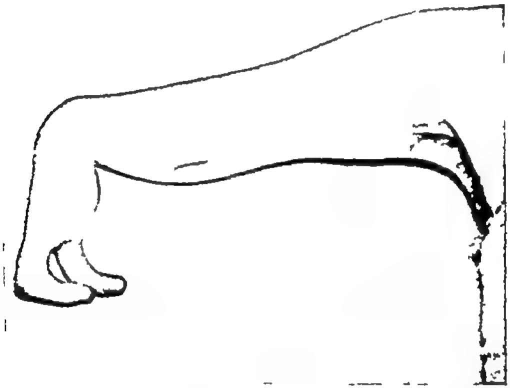

FIG 13.— Congenital malformation of the whole upper extremity showing absence of elbow joint (dimple) Deformed hand which is flexed and two rudimentary fingers attached to the palm. Failure of angulation elongation flexion pronation rotation and digit formation.

shoulder or hip at the elbow or knee and at the wrist or ankle The first and third angles open outwards the second opens inwards

(4) FLEXION AND ROTATION of the whole limb This alteration in form and position affects the two limbs differently and leads to the differentiation of the fore limb and hind limb Each limb is twisted through two-thirds of a circle and the twisting affects all elements—bones muscles nerves etc It is extension or external rotation in the case of the fore limb so that the elbow is directed towards the tail end of the body and forward flexion or internal rotation of the hind limb so that the knee is directed towards the head end

(5) PRONATION A further secondary change occurs in the fore limb Fore limbs are subject to a form of rotation (pronation) by which the radius is made to overlap the ulna and the *fore foot is brought into line with the hind foot* In man this power of rotation is left in an active mobile state so as to provide for pronation and supination

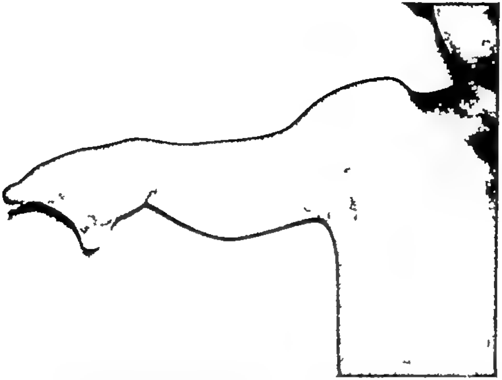

Fig 129 Congenital malformation of upper extremity involving elbow forearm and hand with webbing of the fingers, the thumb and 5th finger being the only digits which have appeared Failure of angulation, elongation and digit formation.

Fig 130 Radiograph of Fig 129 Congenital deformity of arm with fusion of humerus, radius and rudimentary ulna. Only two deformed fingers are present. The remainder are represented by scattered bone remnants

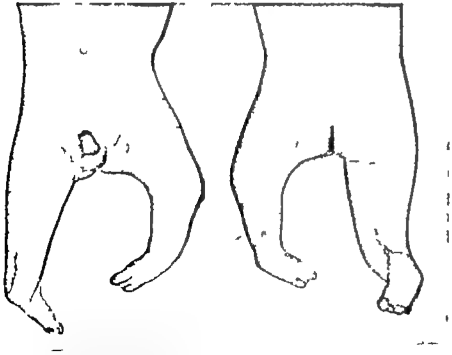

Fig 131 Bilateral maldevelopment of both lower extremities. A combination of failure of elongation, angulation and rotation. Excision of the left knee-joint was required before a suitable prosthesis could be fitted.

such as trauma to or infection of the pregnant mother intra uterine pressure or arrest or retardation of tissue development as a result of nutritional disturbances in the growing embryo

It is of interest to realize that types of congenital malformation which are sometimes genetically determined such as cleft palate and certain skeletal abnormalities can be produced in the offspring not only by maternal nutritional deficiencies and by Roentgen irradiation but also by the deliberate introduction of certain substances during embryonic growth Duraiswami has shown that insulin injected into the yolks of embryonated hens eggs can induce certain congenital anomalies

From the point of view of the orthopaedic surgeon and in particular of those who are concerned with the fitting of artificial limbs in children the derangement of the muscular as well as of the skeletal system becomes important It is not only the abnormality of bone and joint that is to be considered but of the muscles too because abnormalities of muscle growth influence to a great extent the future architecture of the bony skeleton

This short description will suffice to show that many factors genetic and extraneous

Fig 125 Congenital short leg (Peromelia) Unsightly high boot. An extension limb is the most useful form of treatment for this.

Fig 126 Congenital shortening of left lower extremity involving mostly the leg and foot (Segmental defect)

Congenital Deformities

Congenital deformities occur during these developmental changes *in utero*. These may be classified as primary or secondary. Primary congenital malformations are always the result of changes in the germ plasma. They are errors arising from an inherent peculiarity, a weakness or disorientation of the germ cells. They are thus genetically determined and hereditary and can be transmitted through several generations.

Secondary congenital deformities occur in a fœtus which is being normally formed and has no genetic abnormal traits in its germ plasm, the developmental process being altered by environmental disturbances. They can be produced by extraneous causes

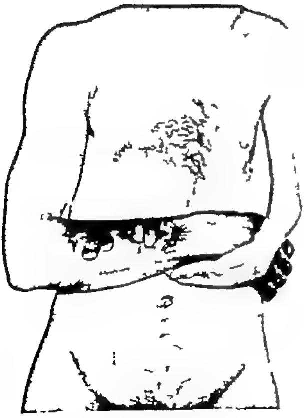

Fig. 133. Congenital hypoplasia of left upper extremity. Unsightly but more useful than an artificial arm.

Fig. 134. Congenital short leg involving right femur. The middle of the shaft is absent and there is congenital dislocation of the hip with failure of development of the head of the femur (Phocomelia).

may influence retard or completely arrest any of the complicated processes through which the developing embryo is passing The exact stage and site at which such changes occur and the extent to which they will influence the developing ovum will naturally affect the anatomical and physiological future of the growing limb and consequently the types and combinations of deformities are theoretically almost unlimited Abnormalities may *thus occur in the growth of the limb buds which result in suppression* hypoplasia or hypertrophy They may also occur in the sequestration of the limb bud resulting in separation or fusion of the segments while the whole limb bud or a portion may fail completely to rotate resulting in an inverted or everted limb or segment of the limb

Malformation of the Limb

From a study of such cases and the scanty literature on the subject the following classification may be helpful —

(1) Smallness of the whole limb—hypoplasia or micromelia
(2) Congenital shortening of a limb may be either proximal (phocomelus) or distal (peromelus)
(3) Congenital *segmental suppression of part of a limb (ectromelus)*
(4) Fusion of the lower limbs (sirenomelus)
(5) Congenital absence of the whole limb (amelus)
(6) Congenital local gigantism

Undesirable Growth of Bone in Children in Relation to Amputees

This may take two forms —

(1) Excessive growth occurring at the end of a stump is caused by continued activity of the epiphysis of amputation stumps with the resultant conical stump

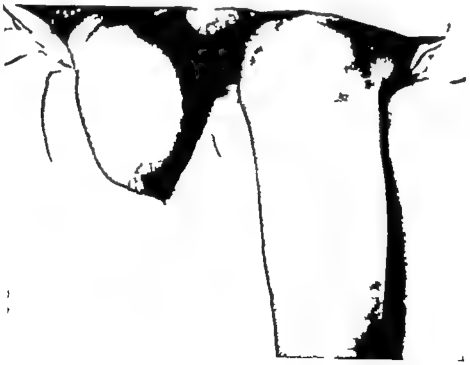

FIG 139 Conical stump in a child with protruding pointed bone tip Epiphysiodesis in addition to re-amputation.

FIG 137 Congenital deformity of both legs. The left is represented by an irregular bone fragment and the deformed bones of the foot (Ectromelia) the right by a deformed rudimentary femur and a tibia but no fibula (Phocomelia)

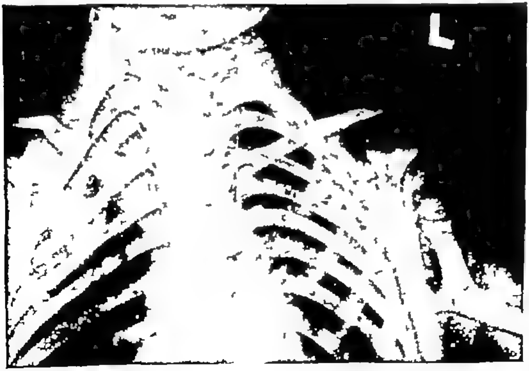

FIG 138. Congenital absence of right arm (Amelia) Scapula and clavicle well developed. There is also congenital deformity of the left arm. The humerus, radius and ulna are fused into one "λ" shape block of bone and rudimentary humeral head is articulating with the under surface of the glenoid cavity Failure of longitudinal division.

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(2) Deficient growth with resulting deformity of the proximal bones e.g the hip and pelvis. Here lack of growth takes place as a result of absence of the normal stimulus In fitting children with artificial limbs some pressure on the growth centres is of great importance This state cannot be achieved without giving child amputees end bearing stumps By end bearing I mean direct pressure on the cut end of the bone or dis-

FIG 140 Fusion of rudimentary tibia and fibula (conical stump)

FIG 141 Bilateral congenital abnormalities necessitating disarticulation of the left leg at the knee-joint and an above-knee amputation on the right. Preliminary plaster pylons made for walking

articulation at a joint This procedure is essential during the growing period and the effect can only be seen by observation over a number of years

When maturity is reached the ordinary type of limb fitting becomes possible although it is sometimes necessary to resort to re amputation at this stage

CHAPTER VIII

THE MANAGEMENT OF SHORT LIMBS AND AMPUTATIONS IN CHILDREN

You cannot teach a man anything—you can only help him to find it

GALILEO

In an adult amputation usually precedes limb fitting, in a child with a congenital defect of a limb limb fitting should be considered before amputation

Discussion of Some of the Commoner Deformities

The surgeon should know what the limb fitter can do as a guide to his management of the case We do not arthrodese excise or interfere with the epiphyseal growth of bones in children as a rule but in conjunction with limb fitting such a course is not only permissible but may be essential

In order to make limb fitting more successful and sometimes possible badly deformed and grotesque limbs can be improved by reconstructive surgery to get better alignment correct deformities and lengthen limbs It should be stressed however that because of the variety of the deformities there can be no standardization of procedure

Children readily adapt themselves to wearing artificial limbs and splints so that it is sometimes possible to accelerate their progress by operative treatment even amputation Surprisingly good functional and cosmetic results can be achieved by early and well-considered limb fitting

It is accepted that the case presented for amputation and limb-fitting is one where the surgeon has satisfied himself that reconstructive operations such as limb lengthening and bone grafting will not prove satisfactory or if they have already been performed have failed to produce a satisfactory limb

Furthermore in such cases it may be found that the joint such as the knee-joint of the abnormal limb does not coincide with the normal one Before amputation is considered the surgeon should realize that as a rule such cases contra indicate amputation and he should provide the patient with a prosthesis which will conceal the deformed limb be of aesthetic value and give a good functional result

For practical purposes, into whatever class a congenital deformity falls what the lay limb fitter has to deal with is a short limb with or without an abnormal joint The limb may be with or without a foot or a hand The hand or foot if it is present may be either vestigial deformed or rarely normal

Deformed joints usually have flexion contractures with resulting diminution of range of movement while owing to a failure of normal rotation the whole axis of the limb may be twisted. In the case of an upper-extremity amputation the child should not be fitted until the age of five or six years Artificial limbs of the upper extremity do not require such frequent repairs as do those of the lower For psychological reasons an artificial limb can be supplied without amputation These are known as extension platforms or prostheses

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Fig. 144. Bilateral congenital deformities of upper extremities. Rudimentary digits have proved useful. See radiograph Fig. 145.

Fig. 145. Congenital deformity of arm. The bones here show practically no resemblance to the normal anatomy with the exception of the phalanges.

The following are some comparatively common types of malformation of the limbs which may require prostheses They may occur singly in any individual or in more than one limb For purposes of discussion they are dealt with singly

They are classified according to the scheme described in the previous chapter and are dealt with not according to their frequency but in anatomical sequence e.g upper extremity lower extremity etc

Congenital Deformities of the Upper Extremity

These are rarely treated by amputation

Anomalous development is fortunately met with less frequently in the upper extremity than in the lower

Fig 142. Complete congenital absence of both upper extremities. A suitable case for kineplastic surgery

Fig 143 Congenital absence of right upper extremity and malformation of left forearm and hand.

FIG. 144. Bilateral congenital deformities of upper extremities. Rudimentary digits have proved useful. See radiograph, Fig. 145.

FIG. 145. Congenital deformity of arm. The bones here show practically *no* resemblance to the normal anatomy with the exception of the phalanges.

inwards The hand may be perfect in formation On the other hand the thumb will be missing where the radius is absent or rudimentary These cases are treated by orthopædic measures to correct the deformity

If the thumb is rudimentary a plastic operation in order to lengthen this important member may be considered A useful prosthesis in which an artificial thumb can be fixed to the wrist is the method of choice

The child should be encouraged to use his rudimentary appendages to the utmost limit of his ability The amazing dexterity thus developed is a matter to be wondered at It is advisable to fit artificial limbs before maximum development has taken place both

FIG 149 Congenital deformity of hand The 4th and 5th fingers are absent and there is no semi lunar or triquetrum.

FIG 150. Congenital deformity of radius and ulna which has failed to separate from humerus. Absence of hand.

FIG 151 Bilateral deformity of both arms. Five fingers are present with fusion of the 4th and 5th metacarpals. There are rudimentary carpals on both sides but the humerus radius and ulna are represented only by an amorphous bone fragment on each arm

FIG 152. Congenital absence of radius Deformity of hand. Congenital shortening of ulna.

FIG 153 Congenital shortening of ulna with Madelung's deformity

inwards The hand may be perfect in formation On the other hand the thumb will be missing where the radius is absent or rudimentary These cases are treated by orthopaedic measures to correct the deformity

If the thumb is rudimentary a plastic operation in order to lengthen this important member may be considered A useful prosthesis in which an artificial thumb can be fixed to the wrist is the method of choice

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Fig 149. Congenital deformity of hand The 4th and 5th fingers are absent and there is no semi-lunar or triquetrum.

Fig 150. Congenital deformity of radius and ulna which has failed to separate from humerus. Absence of hand.

(1) Constriction by the umbilical cord
(2) Amniotic bands
(3) Intra uterine fracture
} Mechanical
(4) Inflammatory condition affecting the limbs of the fœtus
(5) Defective vascularization (Sir A Keith)

The work of Mall and the recent researches of Duraiswami have shown that other factors may also have to be considered

As will be seen congenital absence of a segment of the arm and thigh generally occurs high up in the upper third of the limb In the forearm it occurs in the upper third and in the leg in the lower third Where there is no actual complete amputation a deep circular constriction is sometimes found in the limb Some of these constrictions may be so severe as to cause marked enlargement of the distal parts (congenital local gigantism)

The parents usually bring the child for treatment at a very early age The most important aspect of this early treatment should be directed to reassuring the mother and telling her that she herself will be amazed at the ultimate powers of her child The surgeon should show no anxiety and should instruct the mother to allow the child to develop normally whilst encouraging him to use the stump as much as possible Psychologically such children develop differently from those who have had a segment of a limb amputated because they have never possessed such a segment In these cases surgical interference should be avoided not only from the physical but from the psychological point of view A slightly irregular stump due to a deformed digit or appendage will prove no bar to fitting with a comfortable prosthesis These children develop their ability with these stumps in an amazing fashion When the child is old enough to assume intelligent control of a prosthesis and in the case of the upper extremity is unlikely to injure himself with it an artificial leg or arm with a hand or an appliance can be fitted

T J Age 13

This patient is an intelligent boy who wishes to become a motor engineer

There is a congenital deformity and he has no arms and no forearms but his hands are attached to his scapulæ He has five fingers the thumb is movable on both sides but adducted The usual markings in the hand are practically absent He is able to bring his hands across his chest He feeds himself He has good power in his hands The scapula appear to be abnormal and their spines protrude He has good muscle power in both thighs and in his feet Both knees are ankylosed in about 35° of flexion

5 Congenital Absence of Whole Leg (Amelia) This condition is fortunately rare When it does occur it is usually bilateral Such a child is born with rudimentary appendages which project from the sides of the pelvic floor There is hardly any attempt at limb formation and the appendage takes the form of a toe (phocomelus)

For children with rudimentary appendages of the lower extremity short pylons can be fitted at a very early age say eighteen months or two years of age

The short pylons are later advanced to elephant legs followed by artificial limbs These children can start to walk *pari passu* with physical development Sometimes highly intelligent they develop normally but the prognosis as far as useful walking is concerned is poor Their lives should therefore be planned for sedentary occupations

H D Age 12

She has bilateral congenital deformities of both lower extremities; the right leg is the longer of the two She has a flexion contracture of the hip The fibula is

physically and functionally and to send the child to school looking as normal in appearance as possible in order to protect him against any psychological trauma brought about by his schoolmates comments Generally speaking the most suitable age for fitting an artificial arm is reached when the child can understand and play with mechanical toys

4 **Congenital Abnormality in which a Hand or Foot is Absent, the Limb being otherwise Normal.** These cases occur more frequently in the upper extremity The absent parts are usually the lower two thirds of the forearm and hand The elbow functions normally Occasionally there is an attempt at digit formation or there may be only a dimple on the end of the stump Not uncommonly the defect is the absence of a hand at the wrist as if a disarticulation had been performed These cases were formerly regarded as intra uterine (spontaneous) amputations This is incorrect as no one has ever found a segment of a limb within the uterus These deformities in the past were attributed to —

Fig 154 Bilateral congenital deformities of elbows, forearms, hands and fingers. Notice dimples at site of humero-ulnar junction. See X ray Fig 155

Fig 155. Congenital deformity of both arms with absence of elbow joints. Fusion of rudimentary humerus and radius, the ulna represented by a small bony fragment Three fingers only are present with rudimentary carpal bones on left side and two fingers on right

absent and she has a valgus right foot with three toes. There is a dimple over the front of the tibia which is bowed. The left leg is vestigial. A foot only is present which has four toes exhibiting syndactylism. The whole limb is so short that it appears as an appendix on the buttock. She has congenital absence of her left hand and forearm with a very short forearm stump. The right hand is well developed. No evidence of spina bifida externally and no further abnormality. The overall length of her right limb from the anterior superior iliac spine to the medial malleolus is 15 in. on the right leg and about in. on the left leg.

8. **Congenital Absence of a Part or the Whole of the Femur.** This congenital defect may take several forms. In some cases there is delayed development and shortening of

FIG. 160. Congenital abnormality of both lower limbs with defect in elongated neck of left femur. Fibula absent on both sides.

the whole femur with subluxation of the hip joint or knee. Occasionally these joints are well developed. The upper end of the femur may be undeveloped with a defect of the head and neck, the lower end of the femur being present.

The middle segment of the femur may be absent and the short proximal fragment abducted to a right angle, bringing the knee almost opposite to the normal hip.

The result of the deformity is a shortened leg with an ankle joint opposite the normal knee.

FIG 156. Congenital deformity of both legs. The right is represented by only a small fragment of femoral head. The left shows deformed femur and absent fibula.

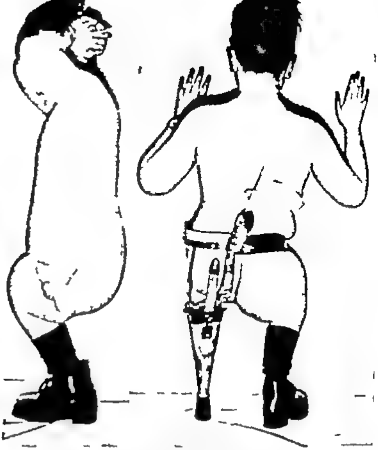

FIG 157 Congenital deformities of both lower extremities with flexion contracture of the right knee Complete absence of the left leg Fitted in stages. Stage 1 tilting table with a peg leg

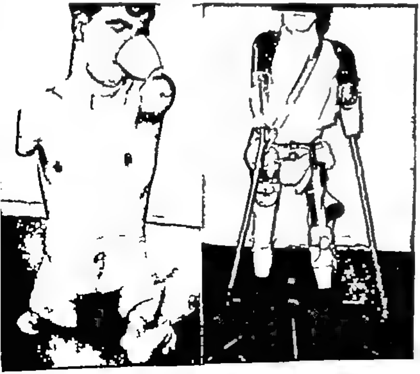

FIG 159 Congenital absence and deformities of all four limbs. The same patient fitted with prostheses.

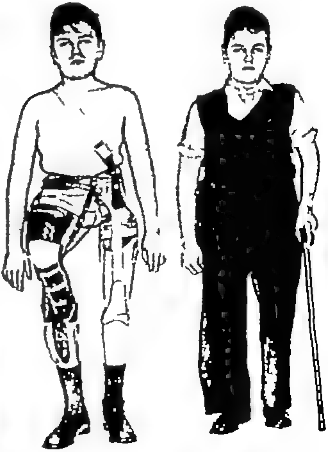

FIG 158. Stage 2. Full-length extension limb on the right and full length tilting table on the left

ing of the whole limb When this is marked it may be possible to fit a conventional above knee limb with good functional effect, this moreover obviates multiple amputations

In 1930 Borggreve suggested a method of overcoming these difficulties He rotated the limb through 180 degrees so that the heel was directed forwards and the toe backwards The muscles then controlled the ankle of the short limb and when fitted with a

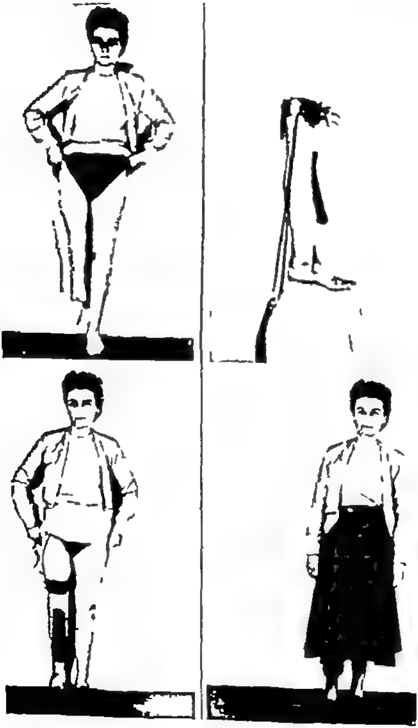

FIG 162 Congenital short leg involving the femur and tibia and an equinus foot A suitable case for an extension limb

TREATMENT These limbs are usually extremely short and it is impossible to lengthen the femur sufficiently to obtain even an approximate length Such children ordinarily have to be content with a caliper which is weight bearing heavy and unwieldy Flexion and extension are the only possible movements at the hip joints As reported by Van Nes walking is tiresome due to the underdevelopment of the hip muscles

A valuable method of treating these deformities is fitting an extension (or platform)

FIG 161 Congenital deformity of the left leg with shortening of all bones. Absence of fibula and developmental failure of ossification in the middle of the femoral shaft

artificial appliance to the deformed limb with or without the vestigial foot This is made to enclose the deformed limb completely and to resemble the opposite normal limb It therefore looks quite natural The need for amputation of the foot depends upon its functional value the stability of the heel and the degree of equinus A small foot a good heel and a high degree of equinus would indicate its preservation while a relatively large foot rigid at right angles and where the heel is unlikely to support the body weight would be an indication for amputation

A Syme s amputation is occasionally decided on depending on the degree of shorten

ing of the whole limb When this is marked it may be possible to fit a conventional above-knee limb with good functional effect, this moreover obviates multiple amputations

In 1930 Borggreve suggested a method of overcoming these difficulties He rotated the limb through 180 degrees so that the heel was directed forwards and the toe backwards The muscles then controlled the ankle of the short limb and when fitted with a

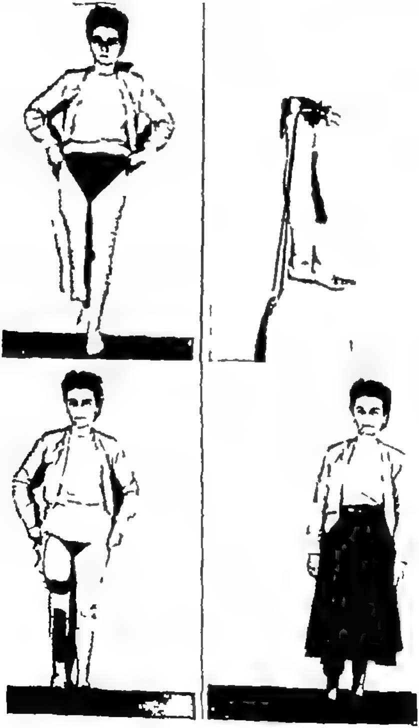

FIG 162. Congenital short leg involving the femur and tibia and an equinus foot A suitable case for an extension limb

prosthesis the foot and ankle were accommodated within the artificial limb and controlled the knee-joint of the prosthesis In the cases reported by Van Nes, the difficulty was two fold apart from the shortening, the gap on the femur had to be bridged

Mrs T Age 41

Congenital short leg

R leg 14 in short of which 7 in. is above the knee and 7 in. below the knee. Stiff hip Good heel in equinus Good knee Straight tibia and fibula Small foot and syndactyly second and third toes

Fitted with a platform limb No amputation was needed even at this late stage

7 **Congenital Short Leg with Flexion Contracture of the Knee (Peromelia)** In a

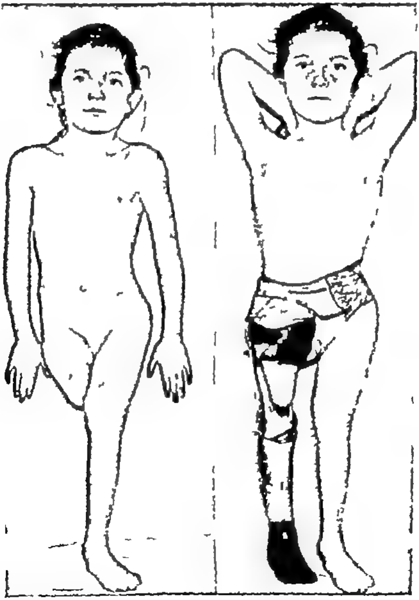

FIG 163. Congenital absence of the leg and foot with flexion contracture of the knee Presence of deformity makes limb-fitting difficult Excision of the knee and later fitted with conventional above-knee artificial limb.

child with congenital absence of the leg and foot or with a vestigial foot a flexion contracture of the knee often exists In its younger days until about the age of seven the child can be fitted with a temporary prosthesis of the above knee pattern The deformity however tends to become worse and the flexion contracture becomes more fixed with a few degrees of movement in flexion If the vestigial foot is present it is amputated immediately above its point of fixation If the vestigial foot has already been amputated the growing end of the tibia produces the conical stump of childhood The hip joint usually has a good range of movement and I have found the following operation to be of value in these deformities —

The conical stump is first attended to A re amputation is performed removing the offending conical apex of bone and if any granulations exist the skin is circularly excised In some cases it is necessary to remove ½ in (1 5 cm) of the tibia before the wound can be closed and sutured satisfactorily An excision of the knee is then performed Through an elliptical incision the joint is opened and the articular surfaces of the tibia and femur are excised In order to obtain good alignment it is necessary to remove a liberal amount of the condyles of the tibia and femur One need not be sparing here as the disturbance which is produced by interference with the epiphysis is helpful in minimizing growth and eliminating the subsequent complication of a conical stump Such irregular growth of the condyles as may occur is controlled by the daily pressure of the prosthesis

When good alignment has been secured it may be necessary to approximate the raw surfaces of the tibia and femur anteriorly with a few thick catgut sutures passed through the bone The wound is then closed with interrupted silkworm gut sutures and a plaster of Paris spica applied to maintain correction and ensure union

FIG 164 Very short leg with flexion contracture of hip and knee Excision of knee and artificial limb fitted

Flexion contractures of the knee are occasionally accompanied by flexion contractures of the hip The head of the femur may be dislocated or there may even be an infantile coxa vara with a pseudarthrosis of the femur The flexion contracture can generally be corrected sufficiently by manipulation at the same time Unless the hip is painful it is unnecessary to interfere with the hip-joint in any way as the prosthesis which will be supplied will be ischial bearing and the amount of additional strain inflicted on the hip-joint will be minimal The dislocation and the growth disturbances can be left to run their own course

The prognosis in this class of case is good When union of the arthrodesis has occurred a standard above knee prosthesis is fitted The child looks normal and walks well He is relieved also of the inconvenience of re-amputation Occasionally it may be necessary to do a subtrochantine osteotomy to secure a normal alignment of the limb

8 **Pseudarthrosis of the Tibia in Childhood (Ectromelus)** This is an uncommon condition where a defect occurs with a pseudarthrosis of one or both bones of the leg usually the tibia

Fig 105 Congenital deformity of lower limb with dislocation of deformed femoral head. Below knee amputation. Pointed conical tibial stump with lines of arrested growth The knee has been excised in order to improve alignment and prevent further coning of stump

The defect is at the junction of the middle and lower thirds of the tibia It is present at birth and manifests itself in the first year of life or soon afterwards It is an unusual type of defect—there is a gap occupied by fibrous tissue between the fragments

The false joint will not heal without surgical intervention because of the gap and the overlapping of the framents and there may be considerable shortening There is usually anterior angulation present at the site The ætiology of this condition is uncertain. The essential nature of the error is an agenesis of a portion of the tibial shaft which most likely originates as a sequel to a nutritional disturbance It has been suggested that it (*a*) arises from pre-existing cysts (*b*) from constriction by amniotic bands (*c*) results from a fatigue fracture of a congenitally abnormal tibia and persists because of mechanical factors The most feasible theory is that there is a deficiency in the nutrient artery with the result that the bone cells fail to develop to their normal osteogenic stage

About 75 per cent of cases yield to operative measures—bone grafts the other 25 per cent remain ununited with the foot in equinus and acute forward angulation at the pseudarthrosis

The latter cases also have considerable limb shortening which can be overcome without amputation by the fitting of artificial limbs The prosthesis can be fitted to encase the deformed tibia and foot and useful limb function is often achieved.

Amputation may become necessary in later years but should be deferred for as long as possible

When congenital pseudarthrosis does require amputation because of great retardation of growth, which may be accompanied by deformity a below knee amputation is most suitable This is best performed through the pseudarthrosis the fibula should be considerably shortened

(i) **Talipes Varus or Equinovarus Associated with Congenital Absence of the Tibia (Ectromelia)** Defective development of the tibia is much less common than that of the

Fig 166 Congenital deformity of leg Three grossly deformed toes are present The tarsals are absent and tibia and fibula are represented by short bone fragments.

Fig 167 Congenital absence of fibula Three toes and rudimentary tarsals.

fibula Generally the femur is somewhat shortened and its lower end imperfectly developed Sometimes the patella is absent, and other malformations co-exist Nearly always there is a flexion contracture of the knee and the fibula may be dislocated backwards The foot is generally in an attitude of varus The toes may be normal, or the great toes may be absent In about a third of the cases a portion of the tibia usually the upper end, is present The prognosis as far as a useful limb is concerned is extremely bad the growth of the leg and thigh being much retarded The deformity of the foot

can usually be corrected, so that an artificial platform limb will provide a more useful support than would the short distorted extremity If the leg is extremely short and deformed and the foot is of no practical use an amputation should be considered A below knee amputation is advisable if the knee is normal, if on the other hand, the knee is not functionally useful, a disarticulation through the joint is the operation of choice

10 **Talipes Equinovalgus Associated with Congenital Absence of the Fibula.** This rare deformity is the most common of the ectromelus class The foot at birth is usually

Fig 168 Congenital absence of upper third of fibula. Normal foot

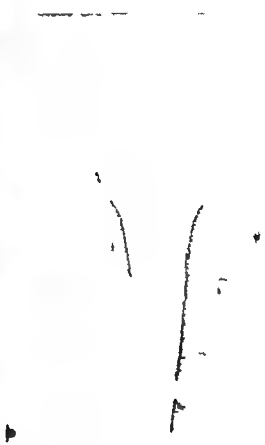

Fig 169 Below knee amputation Congenital absence fibula which is represented by a small bone fragment only

in an attitude of well marked and resistant equinovalgus The leg is somewhat shorter than its fellow and the tibia is often convex anteriorly sometimes at an acute angle at a point somewhat below the centre as if it had been broken At this most important point the skin may be adherent and dimpled Sometimes the foot is perfect but usually one or more of the outer toes with the corresponding tarsal bones are absent

These malformations can be fitted with a platform limb This is an articulated limb of normal appearance which encases the patient's own abnormal limb *The natural foot* rests on a platform which is concealed within the calf of the artificial limb The artificial

foot is erected at the same level as the opposite normal foot Platform limbs are especially suitable where the foot is in marked equinus The shorter the limb the more the clearance available for the artificial limb the thinner the limb the more nearly will the artificial limb resemble its opposite member

11 **Congenital Amniotic Furrows Producing Deformities Absence of Limbs and Conditions which Require Amputation** Tightly constricting bands of scar like tissue accompanied by deep indentations or furrows in the soft tissues of the leg and foot are occasionally seen Such congenital furrows of the extremities are variable in position depth and extent of their encirclement They represent one of a group of abnormalities which may be present alone or in conjunction with other abnormalities in one individual They may be associated with polydactyly syndactyly extradactyly complete absence of a segment of a limb or with gross lymphœdema simulating local gigantism Rarely they may be accompanied by trophic ulceration

It has been suggested that these furrows are due to amniotic adhesions to abnormal development of the germ plasm and probably to congenital changes produced by mesenchymal defects Since these constricting bands may be accompanied by absence of a limb or part of a limb of the foot or of the toes this condition is not now regarded as being produced by external mechanical agencies such as pressure by amniotic bands or by the umbilical cord but it is considered to be caused by lack of vital energy of the early embryonic tissues In animals a similar condition arises as a result of some germinal deficiency (avitaminosis)

Bagg and Little were able to produce congenital defects such as these excluding congenital absence of portions of the distal end of the limbs by treating pregnant mice with X rays Congenital annular constriction of a limb may be produced in animals kept on a diet deficient in vitamin B It has been observed in studying genealogical trees in cases of congenital absence of the limbs that a hereditary germinal deficient factor may also play a part The majority of these cases do not require any treatment

When these furrows are deep and are interfering with the shape and physiology of the limb they should be resected in the circumference of the limb and the edges neatly sutured Any co-existing congenital deformities will be dealt with by the appropriate orthopædic methods An amputation will be resorted to only if all other methods have failed Then it is of the utmost importance that the experience of a limb-fitting surgeon should be sought

When these amniotic furrows are seen in congenitally short limbs they require excision down to the deep fascia The congenital short limbs should be treated as described earlier in this chapter by the supply of an appropriate artificial limb If the furrow is at a higher level than the site at which an amputation is proposed then it should still be excised On the other hand, if the furrow occurs at a lower level (in the region of the proposed amputation site) equal anterior and posterior flaps should be made immediately above the furrow Sometimes these furrows are so deep that excision of skin down to the deep fascia alone will not suffice In these cases they should be filled in by a pad of fat which can be reflected from the subcutaneous layer

This condition may be accompanied by trophic ulceration and a useless lower limb Amputation is then the method of choice

12 **Severe Congenital Deformities of the Foot** Occasionally even nowadays severe deformities as a result of club foot which have had no treatment or in which radical

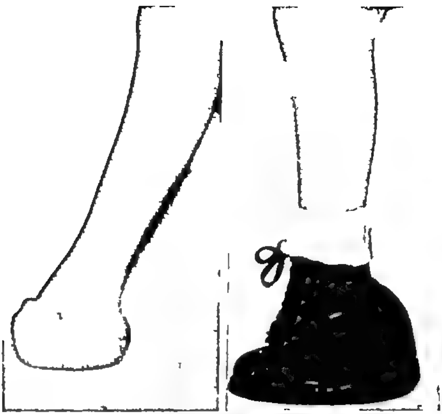

Fig 1 0 Congenital absence of the forefoot with a good heel Foot in varus. Surgical boot. Amputation and prosthesis not indicated here at this age (6 years)

Fig 171 Bilateral congenital deformities. The left leg already amputated—plaster pylon supplied. The right leg —conservative treatment persevered with

Fig 17... R side Tarsals rudimentary Tibia and fibul present L. side Fibula absent Gross deformity of tarsal and only 3 toes.

orthopædic treatment has failed leave the child or young adult with a very disabling limb Extensive operative procedures on such cases leave a limb with a limited function which is short and unsightly especially in a girl In these cases further corrective operations though always considered still leave the patient with a markedly shortened and deformed limb A below knee amputation followed by the fitting of a prosthesis may in exceptional cases give a more satisfactory result

13 **Amputation for Discrepancy of Limb Length** Excellent results can be obtained

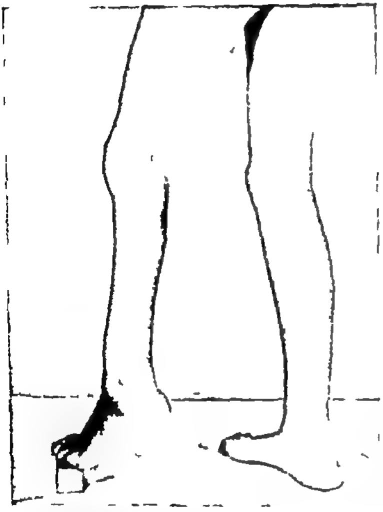

Fig 173. Congenital shortening of leg with equinus foot Leg not short enough and foot too well developed for extension limb Surgical boot

Fig 174 Congenital short leg Unsightly high boot outside iron and inside "T" strap A more suitable appliance indicated No amputation. No artificial limb

by supplying a platform limb in some patients with healed tuberculosis of the hip-joint in which the limb is extensively deformed and shortened following conservative treatment of hip joint tuberculosis or other diseases which require prolonged immobilization of the lower extremity Some of these limbs are as much as 6 in (15 cm) shorter than normal with marked deformity of the foot

Such deformed short limbs due to tuberculosis or other bone or joint disease and which require unsightly high boots may cause mental as well as physical deterioration Some of these do not require amputation being clinically and radiologically healed

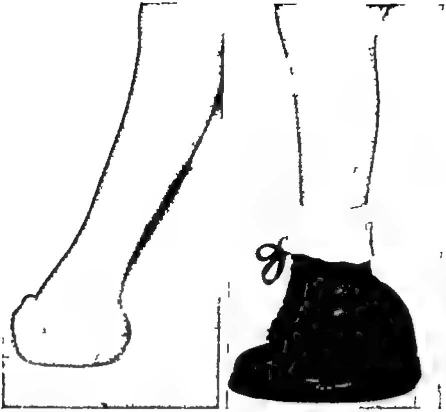

FIG 170. Congenital absence of the forefoot with a good heel Foot in varus. Surgical boot Amputation and prosthesis not indicated here at this age (6 years)

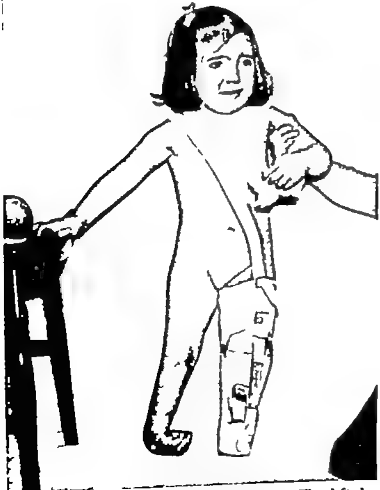

FIG 171 Bilateral congenital deformities. The left leg already amputated—plaster pylon supplied. The right leg —conservative treatment persevered with.

FIG. 1 2. R side Tarsals rudimentary Tibia and fibula present L. side Fibula absent. Gross deformity of tarsus and only 3 toes.

extremely high boots which are unsightly and very heavy. Their problems can be solved by extension limbs which are lighter and much more natural in appearance. There must, however, be sufficient clearance below the foot in comparison with the other leg, viz. 2 in. (5 cm.) below the tip of the equinus.

Amputations may occasionally have to be resorted to in the presence of paralysis, of deformities which cannot be corrected, of recurrent ulceration from chilblains and for useless limbs.

If amputation is considered in such cases, a below-knee operation is nearly always contra-indicated because the quadriceps muscle is weak and the circulation of the leg is extremely poor. The only alternative is therefore an above-knee amputation. It should be borne in mind, however, that the adductors and extensors of the hip must be sufficiently powerful to move a limb. This is of great importance, otherwise a patient

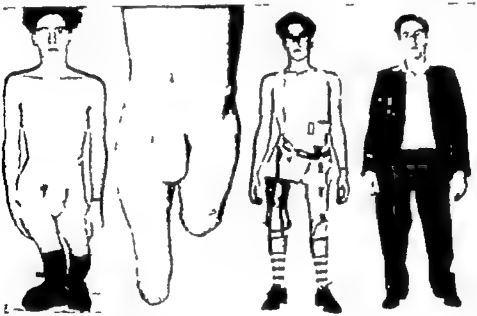

Fig. 1[illegible]. Gross abnormalities. Congenital deformities of both legs with considerable shortening. Below-knee amputation on the R. Above-knee amputation on the L. Artificial limbs fitted. General posture and height improved.

will be no better off with his above-knee amputation and an artificial limb than he would have been with his short leg, caliper and high boot.

An extension limb may well suffice in the case of infantile paralysis where the patient has a flexion contracture of the knee muscles and a flail foot. The leg here is short and the control may be limited to some of the hip muscles. If the adductors of the hip and the extensors are not weak, an above-knee amputation is the method of choice. Poor circulation with a discoloured limb and chilblains are not in themselves an indication for amputation, but when they are present in conjunction with other deformities, extensive paralysis and shortening, the patient should not be denied an amputation in order to persevere with treatment, the outcome of which is unlikely to be more beneficial than an amputation with a good-looking and usefully functioning limb. Sympathectomy in these cases has often proved disappointing.

Miss L. G.

This patient has a short leg due to an attack of infantile paralysis when she

and moderately short An extension limb can then be fitted Though the natural foot is still in equinus, it is within the artificial limb An artificial foot is erected at the same level as the patient's other foot These artificial limbs have corsets with side-steels and knee joints In such cases it is necessary that the shortening should have at least 2 in (5 cm) clearance from the ground with the foot in moderate equinus Extreme conservatism on the other hand should be avoided as it often condemns the

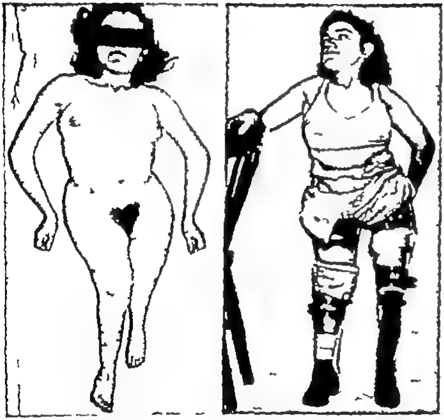

Fig 175 Osteogenesis imperfecta with one leg much shorter than the other Splint supplied for the right leg and extension limb for the left leg

Fig 176 Gross malformation of the leg foot Below knee amputation in such a case advisable.

child to unnecessary and prolonged suffering and leaves him an indifferent limb in which disease may have been only temporarily arrested Chronic infections may necessitate amputation but this will depend upon the site of the disease A chronic infection of the hip for instance will be viewed with more conservatism than a chronic infection of the foot and there will be varying gradations of conservatism depending upon the level of the disease and in addition the extent and site of the infection

14 **Infantile Paralysis.** Not infrequently young adults whose one limb is markedly shortened after early infantile paralysis are allowed to walk about in calipers with

affected muscles are pale and pink Some have undergone fatty degeneration The bones are thin and atrophic In these amputations it is not necessary to suture the deep fascia as skin and fatty tissue make adequate covering to the bone As a rule the skin flaps heal well and give no further trouble

1) **Spina Bifida with Motor and Sensory Paralysis** Cases of spina bifida which require amputation are those in which there has been a meningocele attended to in youth or in which there has been no meningocele but extensive nerve involvement These patients may be incontinent The legs are insensitive have undergone trophic ulceration and are short With a good knee joint a below knee amputation is frequently successful but above knee amputations may have to be considered Amputation should not be resorted to unless there is no alternative It is a rule that skin with trophic disturbances should not be subjected to the pressure of weight bearing

Standard Amputations in Children

Unless the pathological considerations dictate otherwise and there is no needless sacrifice of tissue disarticulation of the joint immediately above the injury disease or deformity is the method of choice End bearing stumps such as through knee amputa

Fig 179 · Disarticulation of the knee in a child. No abnormality

was young The left leg is about 6 in. short rather thicker than the right leg. The foot is in equinus and flail. The abductors of the hip and the extensors are acting, but very weakly The quadriceps has no power The skin of the leg had undergone circulatory changes and ulceration and was subject to several break downs.

Two alternatives were possible : either a platform limb or an amputation.

A platform limb was not advisable as the muscle power which remained in the leg was so poor that the additional weight of the artificial limb and the patient s own limb could not be controlled by the remaining muscle power An amputation therefore, became the only alternative Here an above knee or below knee amputa tion was a matter for discussion. A below knee amputation was undertaken, in spite of the fact that there was a poor quadriceps, with this proviso that the stump was to be very short, the argument being that an artificial quadriceps in the form of an elastic strap could compensate for the weak quadriceps, and the short, below knee stump would then be satisfactorily fitted.

In amputations for these cases of infantile paralysis it is found that the amount of subcutaneous fat is far in excess of that which is usually present in normal limbs The

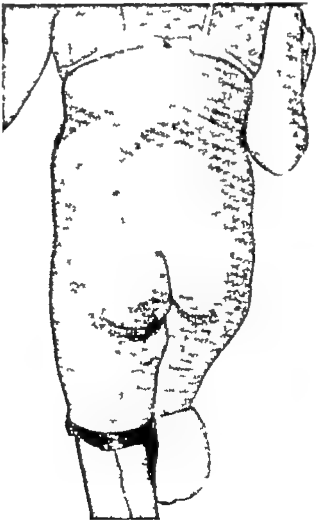

FIG 178. Spina bifida with incontinence and trophic ulceration of the foot and leg Below-knee amputation. Pressure areas in the gluteal region.

in children is the same as in adults except that an excessive amount of skin and subcutaneous tissue should be allowed to cover the end of the bone The end of the bone may be cauterized with a diathermy cautery in an attempt to retard bone protrusion the tightly stretched skin invariably resulting in a conical stump This is a natural sequence to the growth of the upper humeral, tibial and fibular epiphyses which can be so rapid that the soft tissues are unable to grow at the same rate due mainly to atrophy and diminished blood supply The end of the bone then grows into a spike which ulcerates through the skin and produces a red, painful and unstable covering The bone then penetrates through the ulcer base

Control of Undesirable Growth

Epiphyseal arrest may be undertaken to retard the growth of the epiphysis and thus minimize the resultant bone protrusion in an amputation stump in a child This can be accomplished by epiphysiodesis—a procedure which was introduced by Phemister (1933) This is an established operation of value in bone shortening for inequality of leg lengths Various methods have been tried such as (1) excision of the epiphyseal cartilage and insertion of grafts (2) cautery destruction (3) destruction with an osteotome and (4) introduction of staples to produce mechanical retardation of the metaphyseal growth (Blount) As is readily appreciated the weakness of these methods is due to the fact that they can produce unequal bone growth in one direction or another They do not completely stem the growth of bone and later deformities may result which necessitate further operation

There can be no doubt that the epiphyses should be destroyed in spite of the unreliability of the methods

The method which I adopt is to excise through a longitudinal incision a disc of cortex 6 cm × 2 cm × 2 cm crossing the cartilaginous disc and including the epiphysis The sides of the cartilaginous disc anterior and posterior to this are chiselled out to a depth of approximately 2 cm and the transplant is reinserted with its ends reversed

Epiphysiodesis should also be employed in amputations where a flexion deformity exists in a short or misshapen leg In such circumstances the knee joint or the deformity is corrected at the time by for example arthrodesis and the epiphysis treated as described Surgical excision is easy and under direct vision sufficient of the articular surfaces and of the epiphysis can be removed to correct the deformity and also minimize the growth of the bone In such amputations these procedures are more accurate They limit the number of operations and at the same time correct deformities which would otherwise prevent the fitting of satisfactory artificial limbs

It is inadvisable to subject the child amputee to an amputation or a remodelling operation in addition to an extensive epiphysiodesis This operation should therefore be reserved in the case of child amputees for those who require additional operative procedures in the neighbourhood of a joint in order to correct the deformity Epiphysiodesis should be undertaken at the head of the fibula and tibia in below knee amputations where there is adequate length of the stump

Inequality of growth occurs in the amputated segments of a limb which has two bones This is particularly seen in the case of the fibula where the upper epiphysis appears to grow faster The fibula should be resected at a much higher level in a below knee amputation

tions are more dependable than in adults while Chopart's and Lisfranc's amputation should not be lightly dismissed where good sound skin can be obtained and the tendo Achillis lengthened. These amputees walk well. Such procedures eliminate the need for repeated re-amputation to which the ordinary limb amputations in a child are prone. The articular surface of the bone makes a good weight-bearing surface. Disarticulation does not induce such gross secondary structural skeletal changes as a limb amputation.

FIG 180 Right above-knee amputation. The growing stump is beginning to produce a conical outline.

Finally the articular surfaces do not push themselves through the skin and produce ulceration.

If the pathological changes do not fulfil the condition which should permit good disarticulation a transection of the limb should be done. The amputation should be performed at the same level as in adults a good working rule being to amputate at the junction of the upper two thirds and the lower one-third of the limb segment concerned, with the exception that a below knee amputation in a child should also be at the junction of the upper two thirds and the lower one third of the leg. The epiphyseal cartilages should be destroyed. This should be done as a first step in the same operation so that the tourniquet can be released after the amputation in order to attend to hæmostasis. The fibula should be shortened by 2 or 3 in (5 to 8 cm). The technique of amputation

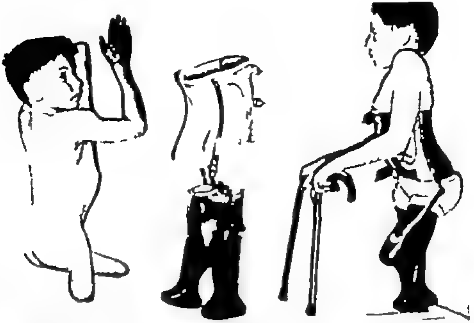

Fig. 181. Congenital aplasia of both legs. Flexion contractures of the hips. Congenital wedged vertebræ with scoliosis. Spinal support fixed to temporary artificial limbs so that he can be taught to walk.

Figs. 182–3. Congenital deformity of upper extremity with manu varum and disarticulation at both knees for congenital deformity of the limbs. Weight bearing artificial limbs.

[Courtesy of J. E. Hanger & Co.

Amputation at an early age affects the growth of a limb. This is seen not only in the length but in the girth of a limb. The bones and the joints atrophy and grow according to the lines of stress and strain to which they are submitted by the artificial limb.

Artificial Limbs in Children

Children can be fitted at an early age, even before they have learned to walk, and so take their primary steps with the aid of an artificial limb. They quickly adapt themselves and do not require extensive training in the use of an artificial limb as adults do.

The clinical analysis which precedes limb-fitting should always be accompanied by an X ray examination, which may help to formulate a sound limb-fitting plan.

Scoliosis, pelvic obliquity and pelvic asymmetry are analysed by X rays and will act as a guide to weight bearing under the load which the pelvis will be obliged to accept. In cases where dislocated and disorganized joints exist, radiology helps to assess the ability of the parts to stand the strain of limb wearing. It is also valuable in flexion deformities of the hip and knee before a reconstructive operation is undertaken.

The appearance of a child's limb is even more important from the psychological point of view than is that of an adult.

Stability in the artificial limb is an essential requirement; the child must feel secure. Children adapt themselves readily and walk naturally and without effort almost immediately after being supplied with an artificial limb. Football, cricket and other strenuous games are easily within the reach of the average child amputee.

Lower extremity prostheses in children should, wherever possible, be made of wood, so that as the children grow the artificial limb can be bisected and an increment piece inserted. This procedure can be carried out easily and quickly. The girth of the limb is usually greater because with the increase in girth of the child's leg enlargement can be carried out in the wooden socket by excavating it to the required size and at the necessary points. If the leg is made of metal the seams can be overlapped, and a limb which is telescopic is constructed. Alterations in the length can be allowed for by riveting the limb at the required level. In young children plastic sockets may be considered more suitable because of the bowel habits of children which necessitate more frequent washing. This toilet problem can also be overcome by the use of wooden and metal sockets which have been cellulosed. As a child is usually fond of playing in water, it is a good practice to make a felt foot which can withstand this.

In a below knee amputation the limb should be made suitable to the requirements of the individual. This is even more important in the above-knee amputation. A child who is fitted at the age of one year usually requires reconstructions of its artificial limb about every six months until the age of three years. Ischial bearing limbs remain ischial bearing for about one month and soon become thigh bearing limbs, but this makes no difference.

Below-knee Prostheses in Children

In the normal child it is not unusual during his school days, when his epiphyses have not yet joined, to find that a traumatic epiphysitis may occur, viz. Osgood-Schlatter's disease. In fitting below knee stumps in children we should bear this in mind because the trauma produced on the epiphysis is great, and we should guard against separation. To eliminate this risk the growing child should not be given the ordinary knee prosthesis

limb maker are essential to enable these unfortunate children to walk and to prevent any further progressive deformity. In unusual cases it may be necessary to combine a spinal support with an artificial limb.

The child who is allowed to attend school on crutches or wearing an unsightly caliper with high heavy boots is considered by his playmates to be a cripple, and as such he is necessarily separated from his fellows and develops a cripple's mentality. His physical development may be seriously interfered with, particularly when he has been allowed to use only one crutch. Here the full weight of the body is borne on one leg at every step, and the pelvis is tilted downwards on the unsupported side and always becomes deformed. Scoliosis inevitably results, and in addition the shoulders become hunched, the chest deformed and contracted, while the free use of the arms is impeded. At the same time the muscles of the stump atrophy and an abduction and flexion deformity rapidly develops, with consequent loss of mobility. Schooldays are unhappy, there is considerable loss of time, and the limb fitter experiences insurmountable difficulty when this might otherwise have been an easy task in fitting and supplying a valuable and natural looking limb.

The continued use of a pylon gives poor results in children. The lack of a correctly articulated foot means loss of support, and the difficulty of maintaining balance on a peg-end results in the body being thrown sideways at every step. There is also a tendency to develop lordosis. The absence of a knee joint forces the child to swing the pylon from the hip in a circular movement, and once this habit is established it becomes more difficult to teach the child to walk correctly on a fully articulated limb.

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which takes most of its weight on the tibial condyles but a thigh bearing artificial limb or even an ischial bearing one

Children become attached to their artificial limbs One girl who was supplied with an artificial limb called it ' Charlie Boy ' On discharge from hospital she begged and cried to be allowed to take her Charlie Boy home with her

Experience has shown that a child with a severe congenital deformity and a short limb should be given the benefit of all orthopaedic measures calculated to improve the anatomical position of the bones and joints After this limb fitting is the best and safest course, assuming that the deformity is sufficiently severe to warrant it Only as a last resort should amputation be undertaken. Fitting should be resorted to sufficiently early to enable the child to go to school This is usually when the child begins to take an interest in constructional toys such as Meccano sets and is between the ages of four and six years

These cases demand a knowledge of the pathological and mechanical needs Assiduous attention to mechanical detail experiment and co-operation with the

FIG 184. The limbs were amputated when this child was six years old and both stumps were fully end bearing As is common in these cases, there was excessive lateral movement of the knee joints particularly in the left leg which showed marked genu valgum when the patient was bearing his own weight.

[Courtesy of Desoutter & Co.

FIG 185 A pair of light metal limbs were constructed with extensible shins to allow for growth and the stumps being fully end bearing the sockets were fitted loosely leaving room for expansion. At the same time the genu valgum deformity of the left leg was corrected.

[Courtesy of Desoutter & Co.

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CHAPTER IX

RE-AMPUTATIONS

"Knowledge when wisdom is too weak to guide her
Is like a headstrong horse that throws the rider."

FRANCIS QUARLES (1592-1644)
Miscellanies

IT is unwise to generalize by saying that specific lengths of amputation stump are so short that they cannot be fitted with a conventional type of limb and that re-amputation at a higher level is necessary in order to make the stump more adaptable to an alternative method of limb fitting. Each individual case must be assessed on its own merits by considering the type of stump and how much stump will remain within the socket in all normal positions and still successfully control the limb no matter how difficult a problem the fitting is likely to prove.

A very short broad stump will not remain within a socket as well as a poorly covered conical stump of the same length.

If the length of stump and the nature of the pathological and surgical conditions are such that a conventional limb cannot be fitted short of re-amputation there may still be an alternative method of fitting a limb by modifying the construction so as to conform to the existing conditions.

The great majority of stumps resulting from open amputations require secondary operative procedures because of their unsuitability for limb fitting apart from their surgical unsuitability.

The general complications in amputations are the same as those for any other surgical procedure. In addition the complications of the disease for which the amputation is performed should always be borne in mind, e.g. embolism including fat embolism and gas gangrene following an amputation for traumatic or diabetic conditions.

There is also a large group of important local complications which result from disease, faulty surgery and unsuitable limbs. The flaps may have been cut short as compared with the level of bone section; sloughing may have taken place as the result of interference with the circulation; the wound may have become infected; the skin may have become adherent to bone or the scar may be exposed to direct pressure causing pain or ulceration; a neuroma or a nerve may be caught up in a scar while chronic infection like osteomyelitis may occur.

Some Complications of Stumps which may Require Re-amputation

(*a*) **Mechanical** (those conditions which interfere with the functioning of the artificial limb). (1) Deformity. (2) Shape (conical stumps). (3) Permanent contractures. (4) Over long stump. (5) Secondary growth of skin and fat.

(*b*) **Clinical.** (1) SKIN. (*a*) Adherent scars plus ulcer. (*b*) Ulcers non-healing. (*c*) Papillomatous hypertrophy of skin. (*d*) Chronic eczematous condition of skin.

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Fig. 188. Above-knee amputation. Irregular bony spur giving no trouble. Excessive and pendulous mass of fibro-fatty soft tissue. (Poor stump.)

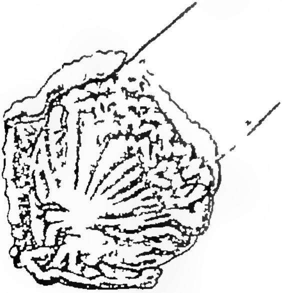

Fig. 189. Amputated femoral stump-segment with skin adherent to the bone.

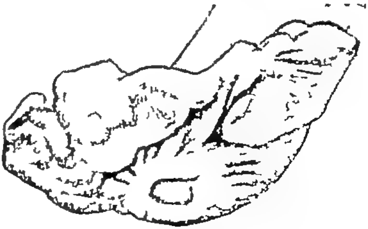

Fig. 190. Amputated stump segment showing ulcer adherent to the end of the bone.

FIG 186 Above-knee amputation covered only by skin. Note the sharp edge on flexion of the stump. (Fitting problem.) An indication for re-amputation.

FIG 187 Long below knee amputation. Conical growth of both bones. Numerous lines of arrested growth.

(2) MUSCLES (a) Deep ulcers and sinuses (b) Flail stumps (atrophy and fatty degeneration) (c) Flexion contractures of joints which have not yielded to treatment and cannot be fitted with an artificial limb

(3) BONES (a) Mal union of fractures of the shafts of the long bones (b) Cross union between bones and terminal ulcers (c) Spurs—painful and complicated by ulcers. (d) Osteomyelitis and sinuses

(4) ARTERIES AND VEINS (a) Excessive length of stump and poor circulation. (b) Gangrene of stump—thrombo-embolic in type which is accompanied by general

Fig 192. Bilateral below knee amputations without bevelling of the tibia. This requires re-amputation.

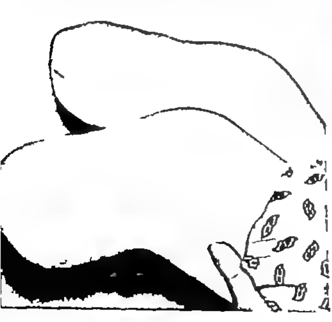

Fig 193 Same case after re-amputation. Note absence of sharp anterior margin of tibia now

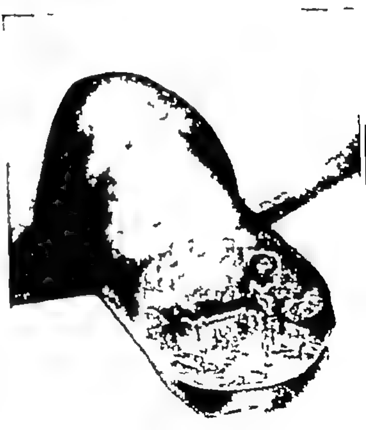

Fig 194 Below knee amputation for thrombo-angiitis obliterans. The tibia has not been bevelled. There n an ulcer over this area and the viability of the stump is poor and it has failed to heal. This stump is also too long

FIG 191 Below knee amputation. Here again spurs have developed from the lower ends of the tibia and fibula The fibula stump is too long and is slightly abducted.

asthenia (c) Vascular changes which have not yielded to treatment (d) Varicosities and ulcers

(5) NERVES (a) Painful neuromata—tender and adherent to scar (b) Phantom pains

During the recent war many amputations presented themselves requiring definitive surgery These can be classified into those which are healed and those which are unhealed. Of those which are healed the minority are satisfactory or with the aid of physiotherapy become satisfactory and suitable for artificial limb fitting according to modern British standards of limb-fitting Those which are healed but unsatisfactory as well as those which are unhealed require re amputation because of —

(a) UNACCEPTABLE LENGTHS Ideal lengths are dealt with in the previous chapter when final amputations were discussed

(b) GUILLOTINE AMPUTATIONS Fortunately the number of amputations of this description which were seen in the Second World War was small Sometimes these had

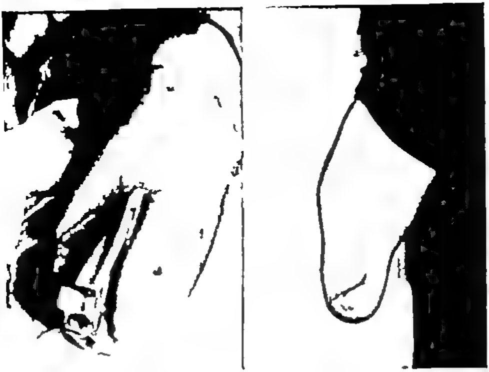

FIG 197 (a) Amputation below the knee with protruding tibia and fibula. (b) Same case after re-amputation.

FIG 198 Below-elbow amputation. A large sequestrum is separating from the ulna. Re amputation.

FIG 195 Chronic ulcer in a below knee stump with muscle forming its base. This will never heal satisfactorily Re-amputation below knee

FIG 196. Chopart's amputation Note the equinus, the end of the stump being weight bearing Poor amputation, especially because of the mechanical difficulty of supplying a satisfactory boot or prosthesis. Re-amputation below the knee

been performed by surgeons not in the British Army My experience with guillotine amputations has not been a happy one They often take a long time to heal necessitating dressings painful to the patient leaving large areas of granulation tissue exposed and requiring at least one or two subsequent operations

Some guillotine amputations have afterwards occasionally been pinch or postage-stamp grafted Although healed the thin papery scars which resulted proved unsatisfactory from the point of view of limb-fitting so in the majority of cases a re-amputation had eventually to be done at sites which were far from ideal. This might have been avoided by the judicious application of an appropriate full thickness skin graft

Skin traction in guillotine amputations did not prove satisfactory in avoiding re-amputations. With the advent of chemotherapy and the antibiotics it seems an unnecessary measure to subject patients to guillotine amputations and I would now

bone and the deeper structures that should be sacrificed not the skin If this is impracticable resort should be made to one of the plastic operations discussed in Chapter X

(4) Thin papery skin scar tissue ulcers and fibrous tissue must be excised while the deeper tissues must be sufficiently freed and dissected until there is a raw bleeding surface which is likely to granulate and become a potential healing base for the superimposed skin

(5) Scar tissue and devitalized skin break down with limb wearing if they are approximated There must be new epithelium and normal skin before satisfactory healing becomes possible

(6) In a below knee stump it may be necessary to remove the fibula although this is undesirable In a forearm stump one of the forearm bones may have to be shortened in order to ensure good healing while in an above-elbow amputation the posterior axillary fold may require dividing to ensure healing and to lengthen an already short stump

(7) The presence of sepsis in the stump will hinder or even prevent primary healing It is a fact which has to be accepted that the lymphatics in such stumps are already heavily infiltrated with bacteria The operation should be delayed if necessary for weeks so that the wound may become as clean as possible

Repeated examination at weekly intervals will be a guide to the bacterial flora and will offer the surgeon some indication as to the ability of antibiotics to control the infection If necessary, a change should be made in the antibiotic if the one in use is not proving satisfactory

(8) When the wound surface is covered with healthy granulations the œdema has settled down and the radiographs show no active periostitis then consideration can be given to re-amputation Œdema especially shows that lurking infection still exists in the intermuscular planes Re-amputation would be performed across infected vessels and the whole problem would have to be faced again It is impossible to exaggerate the importance of this principle The surgical risks are more important than limb fitting and if the surgeon doubts his judgment and ability to convert the stump into a more suitable one he should without hesitation refer the case back to the limb fitter for further alterations in the limb Irrevocable changes occur in misdirected re-amputations which convert the stump into an indifferent and even a useless one

Technique of Re-amputation

All the general principles which have been outlined in the case of a primary amputation still apply but owing to the structural changes which have now taken place and have brought about pathological conditions they may have to be modified

The surgeon must decide whether the re-amputation requires bone section or if a soft tissue operation will suffice by remodelling the skin subcutaneous and muscle tissue Naturally if the smooth healed bone structures are satisfactory both clinically and radiologically and the surgeon s judgment indicates that soft tissue excision and transfer of skin will enable healing to take place this is the operation of choice i e trimming the stump

It is often necessary to deviate from the amputation technique because of unavoidable local conditions but where possible the standard rules laid down should be followed. The operation should be performed under a tourniquet except in the case of avascular

advocate that flaps should always be cut and if there is any anxiety these could be very lightly sutured or not at all

(c) PROTRUDING BONE A small number of cases presented at Roehampton with protruding bone. These were not the results of guillotine amputations which sometimes provided this complication, but were cases where surgeons had amputated at the site of a compound fracture In some the surgeon had omitted to bevel a bone and there appeared no likelihood of satisfactory healing The protruding bone eventually became white lustreless and sequestrated as ring sequestra

As a general rule it is wise to wait until the sequestrum becomes loose: it can then be removed and the stump remodelled by a neat trimming operation

(d) GROSS SEPSIS. The number of cases that had to be re amputated because of gross sepsis was not great, but such cases did occur They were usually at the sites of *compound fractures in the limbs which had comminuted The pus had invaded the* fascial planes and counter incisions drainage and antibiotic therapy seemed unable to eradicate it

Those cases with which we persevered finally required amputation and on the whole I often regretted this perseverance because the eventual stump also healed badly and in the end still proved unsatisfactory

General Principles of Re-amputation

An operation undertaken for a re-amputation is one of great mental importance to the patient Up to this period the actual removal of the distal segment of the limb was required as an urgent necessity for some gross pathological lesion which may have threatened his life Apart from the fact that he has already resigned himself to the loss of his limb he now visualizes that he will have to sacrifice a further portion. He may have become accustomed to limb wearing Usually he has and he knows from experience the importance of saving the end of the stump below the last joint and how this materially affects its function Re-amputation is an operation on which he looks usually with a mixture of hope and fear for he realizes that failure at this important operation will leave him worse off

The general principles which have been enumerated for primary standard amputations still guide us, and should be carefully considered in planning a re-amputation but the anatomy of the stump is now different from the conditions which necessitated the primary amputation. Apart from this the pathological background, which has altered the stump and now makes a re amputation necessary must be given consideration and a planned routine for every case is of prime importance Each stump must now be regarded as a separate entity There is no fixed rule only a few general principles which must be considered —

(1) No matter how short the stump is, it may still be desirable to save it in preference to performing a disarticulation through the joint above, or a re-amputation above the joint

(2) It is most important that the skin of the stump should heal, and that the scar should not be in relation to the front of the artificial limb or where it can be subjected to intermittent pressure If possible it should now be so transposed that it will be subjected to a minimal amount of piston action.

(3) *If a sacrifice* has to be made in order to obtain primary skin healing it is the

gauze to the end of the stump after all obvious bleeding has been controlled. Oozing is controlled by replacing the skin flaps over the end of the gauze pad and waiting three to four minutes. The blood clot becomes adherent to the gauze pad if it is not moved, and generally satisfactory hæmostasis is secured by this method.

Nerves. One should avoid cutting nerves if possible, as they become adherent to the new fibrous tissue. If they are involved in fibrous tissue and densely adherent, they should be dissected away—not separately but with the fibro-muscular pad, as if they were part of the homogeneous mass which indeed they now are. If the neuroma is free and movable it should be considerably shortened and allowed to disappear into the depth of the muscle mass. If the nerve is in relation to a bone, one should not hesitate to follow it and to excise it some distance above the limits of the wound, because pressure on the nerve, placed between the socket and the bone, will eventually lead to painful neuritis or to a tender neuroma.

Bone. If the surgeon has decided that there is insufficient skin to cover the end of the bone without tension he must not hesitate to shorten the bone, if necessary by many inches. This point cannot be over-emphasized. All ends should be bevelled with a saw at first and the necessary bevel made before dividing the bone, as it is extremely difficult to bevel the end of a sawn bone—even more difficult than in a primary amputation. A good plan is to fix the end of the bone with a gauze swab, either in one's own hand or in the jaws of a bone-holding forceps, while the assistant holds the stump firmly above the operation site. Generally the cortex of the bone is thin and atrophic, and is inclined to splinter very easily. The irregular-cut surface of the bone must be carefully filed. If the segment of the limb has two bones, one should not hesitate to shorten one of them considerably, or even remove the whole of a fibula or a radius so as to enable the skin to be approximated without tension. If there are obvious long spurs present, as seen radiologically, and they become exposed at the operation, whether bone section is undertaken or not, they must be carefully removed with an osteotome and the bone smoothed off. They do not always re-form.

Suturing the Deep Fascia. In a re-amputation it is rarely possible to suture the deep fascia. If this can be done, so much the better. However, no unnecessary catgut sutures should be employed to approximate the deeper tissues. The skin should be sutured with silkworm gut or nylon. Great care should be taken to insert the needle at least ½ in. away from the skin edges. This enables the smaller capillaries to induce healing by growing round the skin margin, and thus assist a skin edge struggling to heal. On the other hand, if sepsis develops, the wound will not break down immediately, and the ulceration will not begin once more.

Drainage. A corrugated rubber drain should always be inserted at the conclusion of the operation, and it should be allowed to protrude from both ends of the wound. It should be deeply placed and the blood expressed before the dressings are applied. In spite of good hæmostasis a hæmatoma invariably collects unless this precaution is taken. A tulle gras dressing is applied so as to leave the terminal ends of the drain exposed beyond it; the dresser can then remove the drain in forty-eight hours by disturbing only the top dressings.

stumps or where the primary amputation has been performed for vascular disease The tourniquet is released after the dissection outlined below has been completed.

Skin. This is the important covering which matters a great deal The ulcer the sinus the keloid or the growth should be excised so that a good margin of healthy bleeding skin is left which in the judgment of the operator will enable healing to take place The shape and the obliquity of the scar are now of secondary importance although an attempt is still made to keep equal antero-posterior and symmetrical flaps In dissecting up the flaps two types of anatomico pathological states are seen —

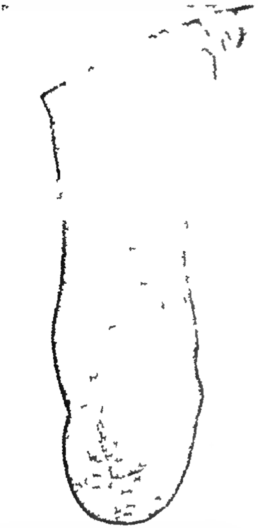

FIG 199 Vertical scar following on a re-amputation. This although not desirable is frequently the only means of saving a below knee stump.

(1) There is the wasted stump in which the muscles are atrophied and the subcutaneous tissue is diminished leaving a mobile skin which can be manoeuvred into position and suitably approximated

(2) There is the thick indurated stump with a large amount of fibrous tissue *in which it is impossible* to separate the skin from the deeper layer as no anatomical plane can now be seen or found This type of stump calls for careful dissection with a sharp scalpel The skin is dissected up together with the fibrous tissue and even a layer of muscle because the vascular supply is now derived from the deep layers and the viability of the skin will depend on them. The thick skin and fibro muscular pad will make a suitable stump covering

At this stage of the operation the surgeon decides whether sufficient skin is available to cover the end of the bone having dissected up two flaps only as far as is compatible with removal of all excess fibrous tissue and muscle The smooth covering of the bone should not be disturbed if at all possible and the white fibro-periosteal mass should not be interfered with as it is Nature's adequate covering If the skin can be induced to heal over it the stump will ultimately prove satisfactory

Muscle The end of the stump now consists of *muscle which tapers off into a fibrous pad* Excess tissue of this type is best excised and trimmed with a pair of scissors It is not easy always to find where the larger blood vessels end To avoid severing them is desirable as embedding catgut in the form of ligature or suture should be avoided as much as possible

Vessels. Division of such blood vessels calls first for ligatures threaded on a needle and then fixation of the vascular trunks to a nearby pad of tissue It is difficult and dangerous to attempt to ligature such vessels without this precautionary fixation

Smaller vessels should be controlled and it is useful to apply a dry pad of thick

gauze to the end of the stump after all obvious bleeding has been controlled Oozing is controlled by replacing the skin flaps over the end of the gauze pad and waiting three to four minutes The blood clot becomes adherent to the gauze pad if it is not moved and generally satisfactory hæmostasis is secured by this method

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CHAPTER X

PLASTIC RECONSTRUCTIVE PROCEDURES RELATING TO AMPUTATIONS

In almost everything experience is more valuable than precept
QUINTILIAN *De Institutione Oratoria* Bk. V Chap. 10

This chapter is included as a guide to those who may not be conversant with plastic surgery and who may be called upon to deal with cases requiring plastic procedures on amputation stumps when other help is not available

As a rule a stump resulting from a well planned amputation does not require the attention of a plastic surgeon Amputations performed for war injuries or industrial accidents however may have been guillotine amputations or there may be extensive skin damage in the vicinity of the stump which makes limb fitting difficult

Such amputations take months to heal the cut end of the bone becomes infected and it may take from twelve to eighteen months before such cases can be satisfactorily fitted with artificial limbs This period may be shortened considerably by plastic surgery which plays an important role in conserving stumps and avoiding re-amputation at a higher level with the accompanying sacrifice of useful joints

Plastic surgery may be required for —

(1) Providing a stump covering of well nourished smooth supple skin with normal sensation and with a scar which is mobile narrow and flat

(2) The elimination of scars proximal to the stump that will not tolerate prosthetic appliances e.g on the thigh or ischial tuberosity

(3) The reconstruction of a segment of a limb or digit

(4) Bone grafts

The following four types of problem may present for decision —

1 **Fitting a Prosthesis to a Stump which had a Preliminary Graft** A stump healed by free skin grafts is unlikely to stand up to limb wearing unless the area of graft is comparatively small and by virtue of being placed over soft tissue is reasonably mobile

2 **Revision of Stump without Shortening the Bone** This usually involves the re-adjustment of the remaining skin so that the adherent or depressed scar is fashioned into a suitable scar that will stand up to limb wearing

3 **Re-amputation** Where sufficient length is available this is the most suitable form of operation to make a stump satisfactory for limb wearing Factors such as blood supply age and general condition will influence the decision as to whether a re-amputation should be considered and whether a joint should be sacrificed and higher amputation performed

4 **Skin Replacement.** If further shortening of bone is contra indicated then the only alternative is skin replacement

Skin grafting of stumps may be —

(1) Free skin grafts in order to obtain early epithelialization —
  (a) Pinch grafts
  (b) Patch grafts (squares)
  (c) Split skin grafts (sheets)
(2) Pedicle skin grafts or skin flaps —
  (a) Local (transposition rotation) These have a very limited use on a stump

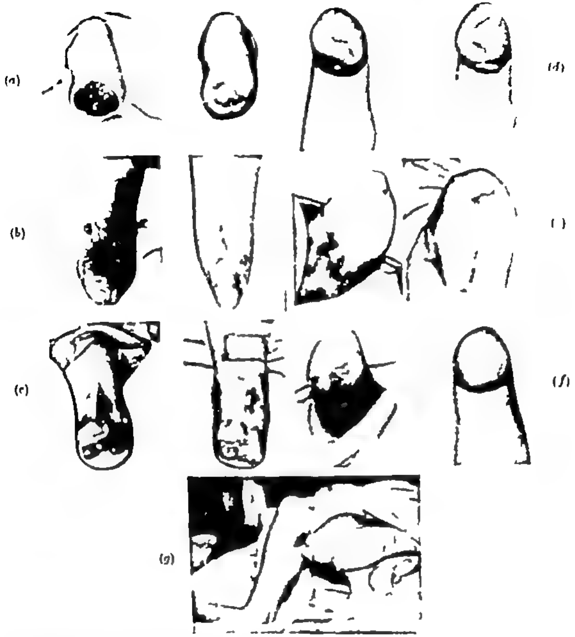
Fig 200 Extensive burns of the right arm and right leg Early skin grafting in order to ensure healing Faulty splinting and flexion contracture of knee No movement of knee. Above-knee amputation the only useful line of treatment

unless redundant skin is available which is very rarely Only small defects can be closed by this method
  (b) From a distance
    Direct—cross leg to below knee thoracic to above elbow abdominal to below elbow
    Indirect—tubed pedicle flap

Guiding Principles in Skin Grafts

1 **Free Skin Grafts.** If following an amputation a stump is short of skin covering treatment should be directed towards securing epithelialization as soon as possible since an infected granulating surface not only delays rehabilitation of the stump but leads to fibrosis and retarded healing The usual procedure of skin traction reduces the area of skin loss but should not be used as a substitute for skin replacement As soon as the granulating surface is suitable for grafting judged by clinical appearance and bacteriological findings it should be covered by free skin grafts either as pinch grafts or as small squares of split skin graft Such a graft may fail to take over the cut end of the bone owing to infection in the bone end but if the remainder of the graft has taken the bone end usually heals over without much delay In the case of amputations through joints there is no cut bone to cover and a good take can be expected

If grafting has been delayed for two or three months dense fibrosis will have occurred with the formation of unhealthy granulation tissue and the chances of a successful skin graft are considerably reduced



(a) Guillotine below knee amputation. Healed by pinch grafts.
(b) A traumatic below knee amputation healed by patch grafts.
(c) A through knee amputation healed by sheet-split skin grafts as a preliminary to a formal above knee re-amputation.
(d) A below knee amputation stump with an unstable adherent terminal scar This is excised and replaced by advancement of a local flap.
(e) An above-knee stump with an unstable scar on the medial aspect This was replaced by advancing skin from the end of the stump where there was an excess.
(*f*) A guillotine below knee amputation stump with a broad unstable terminal scar which was replaced by a *cross leg flap*
(*g*) Showing the attachment of a cross leg flap to a stump.

FIG 201 Some plastic procedures available to make a stump fit for limb-wearing

[From the Dept. of Plastic Surgery Queen Mary' Hospital, Roehampton.

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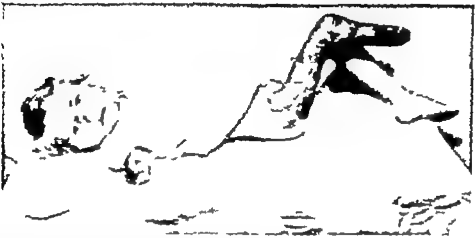

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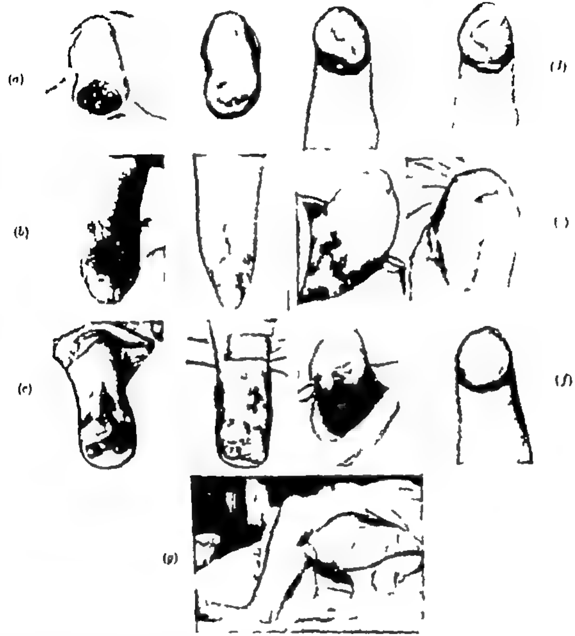

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FIG 202A.

FIG 202B

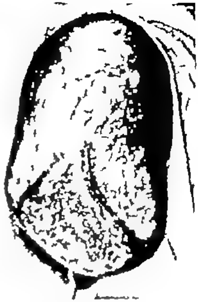

FIG 203.

FIGS. 202A and 202B A short below-knee amputation stump with a large skin defect and sequestrum, later healed by free skin grafts.

FIG 203. A below knee amputation stump three months after amputation, showing the skin defect covered with unhealthy granulations.

[J R. Arott British Journal of Plastic Surgery.

When healed, the stump is reviewed by orthopædic and plastic surgeons with a view to completion. Procedures to be considered are —

2 **Pedicle Skin Grafts or Skin Flaps** (*a*) LOCAL FLAPS There are cases where the skin can be rotated or transferred in a stump so that an important weight-bearing area can be covered by good skin

Excess skin may have been left in one area and can be utilized so that it can be transferred to cover an important weight bearing area On the other hand a stump may be too long and the skin of the end can be transferred more proximally When this important area has healed the distal end of the stump can then be amputated

In planning local flaps advantage is taken of the natural elasticity of the skin which will permit rotation or advancement of such flaps The technique is simple and rapid in comparison with the transference of a flap from a distance

When raising local flaps loosening of skin as far as an adjacent defect must be carried out in such a manner as to allow closure of the secondary defect without causing tension upon the suture line of the primary defect

Local flaps fall into two main groups —

(1) *Transposition Flaps* These find their best application when transfer is effected in a change of plane e g from the side of the finger to the front of the finger or from the side of the stump to the front of the stump

(2) *Rotation Flaps* These permit the transference of adjacent tissue along a curved line on which tension is evenly distributed This procedure may leave a large secondary defect calling for free skin grafting

The field of usefulness of local flaps is related to the size of the defect and to the type of tissue which surrounds it e.g local flaps are satisfactory on the dorsum of the hand but fail on the palm or the sole where the skin is thick

Fig. 204 Large skin defect with papery scar in front

Fig. 205 Papery skin and fibrous tissue excised. Skin edges advanced and sutured.

(*b*) Flaps from a Distance After transplantation the flap must live on its pedicle until new vessels grow into it from the recipient bed

The width of the pedicle must be sufficient to ensure arterial supply and venous and lymphatic drainage Unless the flap contains a large arterial supply its length should not exceed its width

Incisions outlining the flap should be carried down to deep fascia and the flap should be raised by separating fat from fascia in the comparatively bloodless area of loose areolar tissue Care should be taken to avoid unnecessary injury to vessels

In general the line of attachment of the flap should come across the general direction of the vessels so as to receive the greatest possible blood supply

These flaps may be carried from the donor site to the recipient area by attaching them to the forearm hand or wrist or they may be shifted by re implanting one detached end of the flap into a position closer to the defect

Flaps from a distance may be either direct or indirect —

Direct when the flap is raised and transferred direct to the defect (cross leg flap)

Indirect when it is carried to the recipient area by being temporarily attached to a

movable and healthy limb These flaps are either open presenting a raw area on the undersurface or closed by one of three methods —

(1) By tubing the flap
(2) By skin grafting the under-surface of the flap
(3) By covering this under surface with another skin flap

Open direct flaps may be transplanted at once The vitality of such flaps may be doubtful —

(1) When the length of the flap exceeds twice its width
(2) When it is twisted or kinked.
(3) When it is cut transversely or counterwise to the direction of the blood-supply or when it crosses the mid line of the body

FIG 206. A guillotine amputation stump treated by the cross-leg flap procedure
[J R. Arott, Brit sh Journal of Plastic Surgery.

Direct flaps can be transplanted more quickly and easily than flaps like tubed pedicle flaps which take a long time to complete They also considerably reduce discomfort

The Apparent Defect and the True Defect

The true skin defect is not represented by the size of a cutaneous scar The area of subcutaneous scar always exceeds that of cutaneous scar because the skin has been drawn over the wound during the process of healing

In planning a flap notice should be taken of the following points —

(1) The operation should cause the patient as little discomfort as possible e g both hyperextension and hyperflexion of joints would cause pain

(2) The transfer should be accomplished expeditiously

(3) The skin flap should be taken from a suitable donor area which should be chosen with care and *with particular reference to pressure* from the artificial limb

The best match of skin texture and thickness is achieved when the skin of a similar region is utilized e g a cross leg flap

Technique Common to all Flap Operations

(*a*) Careful choice of time for flap transfer This will vary from three to six weeks after the primary operation
(*b*) Elimination of raw areas wherever possible
(*c*) Meticulous hæmostasis
(*d*) Careful suturing

There are several methods of transferring a flap of skin from a distance (1) by using

a tubed pedicle skin flap with the wrist as a carrier from the chest or abdominal area, or from the thigh on the same side (2) by using another donor area when available and when the skin can be utilized from the end of a stump which is excessively long and is to be re-amputated later For instance in the case of amputation above the ankle to be replaced at a later date by amputation below the knee and in which there is scarring below the knee the healthy skin on the segment which is redundant may be utilized for this purpose

The causes of failure in skin flap transfer are (1) inadequate pedicle tissue (2) circulatory failure due to excessive torsion or tension (3) infection as in old osteomyelitis areas

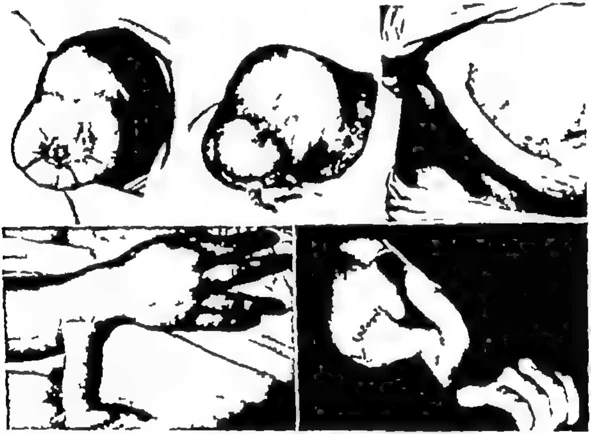

FIG 70 Shows stages of skin transfer from an abdominal tubed pedicle graft via wrist to below knee stump.

(J B [illegible] British Journal of Plastic Surgery

or too early reconstruction surgery after an infection (4) vascular insufficiency or venous stasis in the recipient limb

1 **Treatment of Limb Proximal to the Stump** The limb proximal to the end of the stump may be scarred Such a scar should be excised and replaced by a flap of skin and subcutaneous tissue It is preferable to use the opposite limb as a donor site rather than to extend the limits of the scarring on the amputation stump

There are three sources of pedicle flaps for the thigh The upper and lateral portions can be supplied by abdominal tubed pedicle skin flaps The medial and lower portions are accessible to flaps from the opposite thigh or calf

In a below knee stump excision of a scar and closure without tension is usually possible after sufficient excision of underlying soft tissue and bone but occasionally a pedicle flap is required Wherever possible the plastic flap should be a full thickness

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(1) Careful choice of time for flap transfer This will vary from three to six weeks after the primary operation

(2) Elimination of raw areas wherever possible

(3) Meticulous haemostasis

(4) Careful suturing

There are several methods of transferring a flap of skin from a distance (1) by [illegible]

The ulcer is then carbolized to minimize contamination during the operation *Systemic* chemotherapeutic agents as determined above are given It is important to excise *all* scar tissue The size and position of the flap already marked out on the other leg is again checked and the flap is then raised and tried in position A thick Thiersch graft is cut and applied to the donor area of the flap It can be held in position by marginal anchoring sutures tied over a carefully adjusted flavine emulsion wool dressing Light pressure and further local fixations are obtained by a covering sheet of Lastonet stuck to the skin with Mastisol

The flap is then carefully sutured in position on the stump and the splint is applied

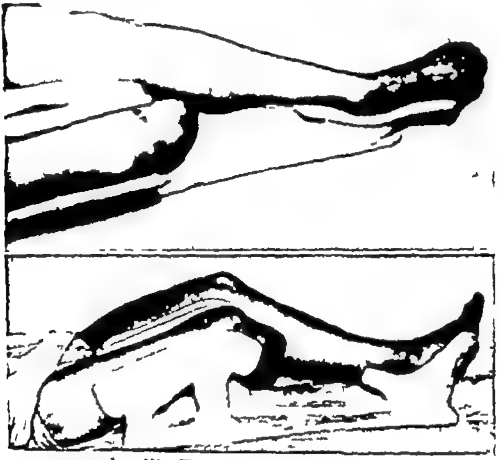

FIG 209 The limbs in position in the splint
(J R Arndt British Journal of Plastic Surgery)

and secured The position is again checked Minor adjustments can be made by padding within the splint *A light pressure dressing is then applied* The flap should be inspected *a few hours* after the operation to check the position and exclude hæmatoma formation To relieve the cramp which will follow as a result of joints being immobilized massage is given several times daily The sutures are removed in ten days time and the graft dressed. Three weeks after the first operation the flap should be soundly united to the stump and ready for detachment from the donor leg

Second Operation. The flap is divided across its base before the splint is removed On the leg the small area of granulation tissue which now exists is excised and penicillin powder is applied The skin edge is sutured to the graft edge The stump is similarly dealt with The flap is trimmed and neatly let in to the remaining defect Sutures are

skin flap because it may of necessity have to be placed over an area where it will be subjected to constant pressure

2 **Treatment of the End of the Stump** Cross leg flaps are the best for supplying skin to the end of a below knee amputation stump They provide a simpler method of supplying skin to below knee stumps than tubed pedicle grafts The stages and time taken are reduced and the patient is more comfortable The indications for this procedure are (*a*) long-standing terminal ulcers due to skin shortage in stumps of minimal length, (*b*) repeated breakdowns of an unstable terminal scar on a stump in spite of limb-fitting

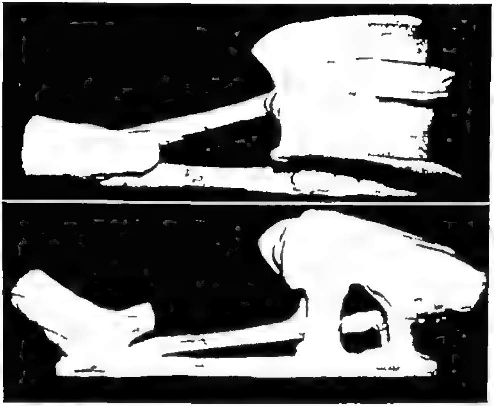

FIG 208. A prefabricated plaster splint for the cross-leg flap procedure. [*By D. Wilde.*

adjustments to relieve pressure These terminal ulcers may be adherent to bone and may have persisted for a long time

Bacteriological examination is carried out to determine the invading organisms and their *sensitivity to chemotherapeutic agents and when infection has been controlled* (penicillin therapy has proved a great help) the operation should be planned in detail. The area of the scar to be excised is marked out The ulcer is then covered with a small sterile dressing and a pattern of the estimated defect is cut in oiled silk. A suitable position of the legs is chosen to give maximum comfort to the patient The donor site should be selected so that the secondary defect will not lie directly over bone The pattern is tried in this position adjustments are made and the position is finally decided upon A removable plaster gutter splint is made which will eventually hold the legs in this position for the necessary time The pattern should again be tried with the splint in position and the outline of the proposed flap is accurately marked out on the donor leg

First Operation. The area of scar around the ulcer to be excised is outlined in ink.

13.11.50 Stump had continued to discharge from a point in the suture line.
X-ray showed no bony cause for this.

16.11.50 Operation (Dr. J. R. A.)
Sinus on stump explored—lead to small subcutaneous cavity. No exposed bone or buried suture found. Cavity thoroughly curetted, opened and packed.
Sinus in left groin curetted. No foreign body found.

The patient was discharged from hospital in January, 1951, after being measured for an artificial limb.

He was readmitted to hospital in April, 1951, complaining that the sinus at inner edge of the flap continued to discharge.

On 7.6.51 the sinus was excised to a depth of ½ in. and dense scar in the base of the wound was excised. No definite foreign body was identified.

The sinus persisted for several months and a further exploration was considered necessary.

On 8.8.51 a further operation was performed (Mr. H. L. R.). A ureteric catheter was passed into the sinus and it was found possible to pass it backwards and upwards to the posterior aspect of the stump. An ellipse of fibrous tissue was excised from the ostium of the sinus and a track of granulation tissue found and traced backwards (with the catheter *in situ*). Eventually a smooth lined space was opened up at a depth of the full length of the index finger. The fibrous tissue and granulations appeared to end here and the end was cut across with scissors and pulled out. An undiscovered ligature was found at the end, presumably the cause of the chronic infection.

Two months later the wound was healed and the patient started limb wearing with tuber bearing corset. The stump has remained healed and the patient is now back at work.

Infolded Scars. For reasons not under the control of the surgeon, the original amputation may give rise to infolded irregular scars. Because of the undesirable sequelæ in these scars, such as intertrigo, ulceration and eczema, they should be excised. Excision is not easy here, *owing to the fact that the perimeters of the skin edges are unequal and the skin* is often inadequate in one part and excessive in another. These scars should be mapped out before excision, excised right down to fibrous tissue, and carefully re-sutured, satisfying the following points:—

(a) The ultimate scar line should not lie in the pressure area.
(b) Planning should aim at preventing the scar from adhering to bone or nerve.
(c) The suture line should be made with an eversion suture to counteract the inclination of the scar to become infolded again.

Drainage should be instituted after careful hæmostasis. *Post-operative treatment* should be directed towards keeping the scar mobile by gentle massage as soon as possible after the stitches are out.

If the bone is found at the time of the operation to have become irregular, it is wise to free a cuff of surrounding muscle and remove about an inch of the bone with its projecting spur. This is a justifiable sacrifice and does not as a rule require any alteration in the artificial limb.

Amputations for Un-united Fractures

Un-united fractures of the tibia and femur which have been grafted or plated and on which there have been many operative procedures occasionally come to amputation

again removed about ten days after the operation and the graft is massaged with lanoline cream When soundly healed, stump exercises and deep rotatory massage of the flap are started The stump should be kept firmly bandaged for at least two months, to allow the flap to consolidate the limb stump then being ready for limb fitting It is of

Fig 210 A cross leg flap ready for detachment.
[J R. Aesti, British Journal of Plastic Surgery.

the utmost importance that the limb specialist should co-operate by designing his instrument so that no undue pressure or friction on the flap occurs

The following case report shows the importance attached to saving a joint in order to fit a limb and the value of plastic surgery in these cases

Case Report Patient Mr J C

This patient had a guillotine amputation performed in 1947 of his left leg below the knee When seen in 1950 he still had an unstable scar at the end of his stump and it was decided that to save the knee-joint it was necessary for him to undergo a series of plastic procedures. Accordingly the following procedures were carried out :—

30.8 50 Splint prepared Flap planned 3 in wide and nearly 2 in long, base below

31.8 50 Operation Dr J R A.
Terminal scar of left below knee stump excised Three infected pits explored and found to contain unabsorbed suture material. No bone exposed
Flap from inner aspect R leg raised according to plan
Thiersch graft to secondary defect Flap sutured in position Fixation by previously prepared splint

21.9 50 Operation Dr J R. A.
Flap divided donor area R. leg trimmed and skin edge sutured to graft. Flap let in on stump after excising granulations

FIG 211 Gunshot wound Bilateral amputation of forefeet Full thickness graft to cover exposed and tender areas.

1 **Fingers** Traumatic amputation of the tip of the finger is a common industrial and domestic accident Here the top of the nail and usually part or the whole of the pulp has gone Treatment other than immediate grafting gives slow convalescence and an unsatisfactory result If the amputated part is available and fresh then suturing and firm pressure will usually produce an excellent result Otherwise there are two courses open either a Wolfe s graft is applied after trimming back the exposed surface of the phalanx or if there is great loss of pulp substance the whole finger may be flexed into the thenar eminence and a direct pedicle flap from that region applied The advantage of the latter is that in addition to full thickness skin sufficient fat can be taken beneath the graft to reconstruct the pulp

2 **Hand** From time to time injuries will occur to the hand when the anatomy of the palm is so damaged as to be beyond repair yet the thumb remains intact and conversely where the thumb is destroyed yet the palm and fingers remain intact Such injuries are uncommon but when they occur the whole hand is usually lacerated Such injuries are seen both in industry and following gunshot wounds

A prosthesis for the leg will at least maintain stability but no matter how skilled or ingenious the instrument maker may be a prosthesis for the hand can never reproduce a hand or finger in which a sense of touch is present

When dealing with injuries of the hand one must adopt a certain conservatism and here particularly it must be emphasized that the more severe the injury the greater the need to be conservative One cannot replace the structures a month after they have been removed All that is done immediately after the accident is a minimal *débridement* with suturing of the skin edges if found unsuitable for suturing the wound may be left open Any small defect that remains may be covered later with a split skin graft The work of constructing a useful hand now begins and from this point onwards one must

In the thigh an amputation can usually be performed through the site of the pseud arthrosis more especially if there remain about 6 or 7 in. of femoral shaft depending of course upon the thickness of the thigh at that level It is best in these cases to remove any screws or metal which are still present as by this time the patient has already had sufficient operations and additional operative procedures are to be avoided. A word of warning is that the amount of fibrous tissue which is present may be excessive and the amount of bleeding which ensues post-operatively can be difficult to control.

In below knee amputations the skin of the front of the leg has usually been scarred. It is best to excise this scar tissue and skin and to fashion the flaps in the below knee stump so that they are continuous with the old skin incisions even though they may not be antero posterior and symmetrical Frequently by such a procedure an above-knee amputation can be avoided and a serviceable stump obtained

Occasionally an un united compound fracture of the tibia exists in which of necessity longitudinal incisions have been made over the anterior surface from previous operative procedures such as bone grafts or platings. If the knee is still useful and we do not require more than 90 flexion it is worth while trying to save the knee for a below knee amputation Here such an amputation does not merely involve the removal of the segment of the limb by conventional means but a surgical procedure in which enough skin is saved to provide adequate covering for the scarred areas The ulcer the unhealthy tissue and fibrous tissue must be excised down to bone As much skin should be saved as possible in order that the ultimate healing of the wound is by a linear scar which does not lie in front of the tibia.

If the previous unsuccessful surgical procedures have resulted in deep gutters in the substance of the tibia the fibrous tissue should be removed by curettage It is permissible, then to remove the medial border of the tibia to allow the soleus and gastrocnemius muscle mass to be sutured into the medullary cavity by a few well placed interrupted sutures It is important to remove much of the tendinous portion of the peroneal muscles because they readily slough, having a poor blood supply The scar is now vertical instead of horizontal and the skin should be sutured as a full thickness layer well away from the edges in order to avoid sloughing from subsequent sepsis or diminution of blood supply

Amputation of *Toe* or *Toes* with some *Toes Standing* and a *Painful* or Papery Scar on Dorsum of Foot

In these cases the remaining toe or toes may become deformed or painful. They are a hindrance and have very little if any functional value

It is good policy to amputate these toes by filleting the bone through a dorsal incision and utilizing the good normal skin as a transposition flap This can be made through a dorsal incision. The skin is filleted from the bone and tendons and disarticulation is carried out at the metatarso phalangeal joint. The plantar skin flap can then be transferred in such a way as to replace the excised scar

Upper Limb

So far we have confined our remarks to plastic surgical procedures and their relation to the lower limbs We end with mention of their application in amputations in the upper limb

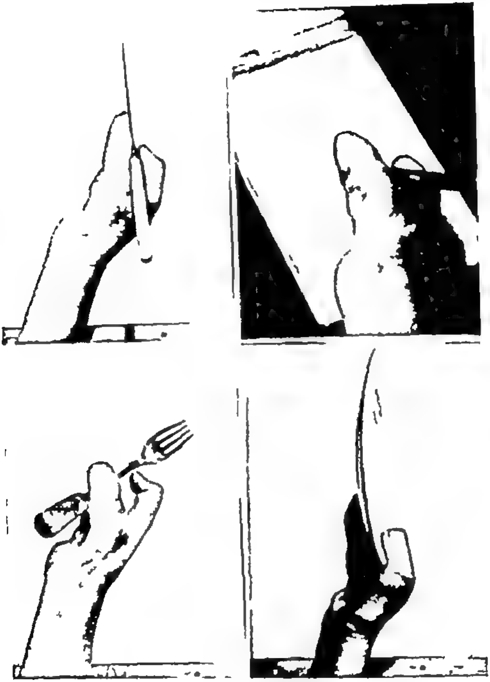

FIG 213 Index finger transposed to position of amputated thumb with good effect
[By courtesy of M R. McCash.

tendon through the peg This cannot give movement to the peg itself but does strengthen the flexion of the whole carpus with its attached peg This will be a hand with which it is possible to pick up small objects hold tools etc So far unfortunately opposition is between the edges of the post and the thumb A rotational osteotomy of the base of the first metacarpal will result in improved function opposition then taking place between the pulp of the thumb and the front of the post

(2) The second problem is when two or more digits remain but the thumb has been destroyed Here results a hand with its usefulness decreased because of the absence of the movement of opposition i e of the thumb In other words what is required is to

remember that function should come before all cosmetic considerations. The aim is to obtain normal palmar sensation in the part that remains, as this will be greater than any that may develop in a graft. Bearing this point in mind, let us consider the following problems:—

(1) *The first problem is one in which the structures of the palm have gone.* A prosthesis may be fitted to be used with the thumb, but this, as we have said, is a poor substitute; therefore one may fashion an artificial palmar stump or a palmar post. Every piece of skin that can be salvaged from the wreckage will be of use. When the

FIG. 212. This is a reconstructed thumb and "prehensile" fingers reconstructed from the metacarpals. The value of this is negligible. More especially its æsthetic value in a woman is poor. Below-elbow amputation.

primary lesion is healed and all sepsis eradicated, the construction may begin. A skin tube is made ready for transference to the hand. Next the palmar skin is fashioned to make a flap. The skin tube is now attached to the hand at the site of the amputated index finger and *in apposition to the thumb.* *A bone graft is then taken from the iliac crest* and shaped to the form of a peg. The skin tube is opened and a slot cut in the remaining carpal bones. The graft is then fixed firmly in the slot and its angle of inclination adjusted to give a maximal functional result. There is now a bony peg extending distally from the carpus, covered by a fat lined skin tube. It may be possible to give increased movement to the post by fixing either a flexor digitorum profundus or sublimis

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reconstruct the thumb The most satisfactory procedure is to fashion a digit with its metacarpal into the thumb—a procedure known as pollicization This procedure like the former will require several stages These will not be described in detail, but the essential points are the nerves and blood supply and the tendons must be transferred intact A carefully planned pedicle graft will need to be inserted to form a satisfactory web which will not contract If available attachments of the small muscles of the original thumb will give increased function The end result of this operation of pollicization is functionally very satisfactory The transference and fashioning of flaps are such that it is very much the work of the plastic specialist and not the orthopaedic surgeon

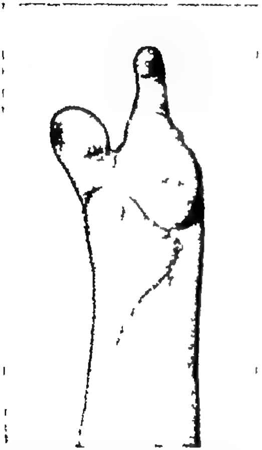

Fig 214 Reconstruction of a thumb in spite of the fact that the remaining middle finger is deformed and stiff No apposition possible. Below-elbow amputation.

3 **Forearm.** Procedures with regard to stump scars and proximal scars that make the wearing of a prosthesis difficult mentioned in relation to the lower limb apply equally well here There is however one manoeuvre that might merit attention Because of trauma it may be necessary to amputate a forearm at such a level that it is impossible to fit a prosthesis The patient will have insufficient stump to enable him to flex and extend his elbow the mechanical leverage not being sufficient to make it possible The length of the stump may, however be increased by means of a tubed pedicle flap A bone peg is inserted through the tube into the short ulnar stump The movements of this stump may be small but when transmitted to the end of the prosthesis may well give the patient 20° to 30° of flexion and extension

These procedures necessitate several operations and consume a great deal of the patient's time but the functional result is I feel well worth the time worry and effort of both patient and surgeon. The type of grafting used here particularly in the hand is not just the simple split-skin graft practised by most surgeons but tubed pedicle flaps the care and successful transference of which depend not on text book knowledge but upon the skill and experience of the plastic specialist in whose care these patients should be placed

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CHAPTER XI

OPERATIONS ON AMPUTATION STUMPS DESIGNED TO ENLIST RESIDUAL FUNCTION

"No idea is wholly new; what is new is getting people to adopt it and to act upon it."
HARVEY CUSHING.

Upper Extremity The human hand has certain particular qualities, to some of which no artificial hand can possibly attain —

(1) Sensation—response to stimuli such as touch heat and cold, position sense

(2) Intricate muscle movements in their manifold permutations and combinations, of which the human hand is alone capable

We try to imitate some of the lost functions—

(1) By plastic procedures designed to improve the unsuitable stump and thus render it more efficient in the management of the prosthesis (see Chapters IX and X)

(2) By operative procedures designed to utilize sensation and the power of the remaining stump muscles as a claw as in the Krukenberg procedure or by utilizing the remaining muscles as a means for activating an artificial hand as in kineplastic procedures, to be described later

Operative Procedures

The special operative procedures may be listed as follows —

(1) Amputation combined with arthrodesis of the shoulder
(2) Kineplastic surgery
(3) The Krukenberg forceps operation
(4) The enlistment of pronation and supination by —
  (a) Putti's method
  (b) Henry's method
(5) Neo-arthrosis of the shaft of the humerus.

1 Amputation Combined with Arthrodesis of the Shoulder

Complete Irrecoverable Brachial Plexus Lesion (Lesion in which the patient's arm is intact and viable but useless) The results after repair of the brachial plexus are poor even in the best hands It is difficult often impossible, to dissect out the torn nerve roots and trunks from the matted mass of fibrous tissue, and even re-sutured they seldom show recovery

After a varying period of two years or more the unfortunate patient is left with a heavy immovable partially insensitive useless limb which is often ulcerating The victim demands relief (Figs 215 216) Fortunately in most of these cases the scapular muscles still retain their nerve supply There is still control of the scapulo-thoracic movements by the trapezius the rhomboids the levator scapulæ and sometimes the serratus magnus (Fig 217) Some of these cases require amputation

Fig 215

Fig 216

Figs 215-16 Complete irrecoverable brachial plexus lesion with ulcerating useless arm.
[illegible]

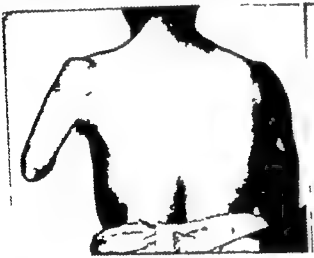


Fig 217

Fig 218

Figs 217-18 Complete irrecoverable brachial plexus lesion after arthrodesis with amputation
[illegible]

The arm is amputated about 6 or 7 in (15–20 cm) below the acromion and at the same operation an intra articular arthrodesis of the shoulder is performed The ulna in the amputated segment is dissected out and used as a graft for stabilizing the arthrodesis

Through a sabre-cut incision (Fig 218) the deltoid being already paralysed the shoulder joint is opened up and denuded of the articular cartilage on the glenoid fossa and the head of the humerus

The triangular-shaped ulnar graft about 5 in (10–12 cm) long is then driven through the anatomical neck of the humerus into the head and well into the glenoid fossa The arthrodesis is fixed in plaster in about 45° of abduction and 15° of forward flexion (Fig 219)

The stump is firmly arthrodesed in about six months (Fig 220) These patients can

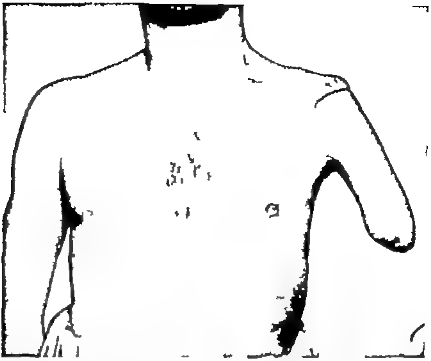


FIG 219 The well-shaped ulnar bone graft about 5 in. long is then driven through the anatomical neck of the humerus into the head and well into the glenoid fossa. The arthrodesis is fixed in plaster in about 45° of abduction and 15° of forward flexion.

[Reprinted from Ann. Roy. Coll. Surg. Engl.

FIG 220. Radiograph of this case

[Ann Roy Coll. Surg Engl.

then be supplied with an upper arm prosthesis which they can control by their remaining scapular muscles

I have performed thirty such operations with success Similarly bone grafts have been used from the amputated segments for arthrodesing the hip joint in flail above knee stumps amputated for infantile paralysis

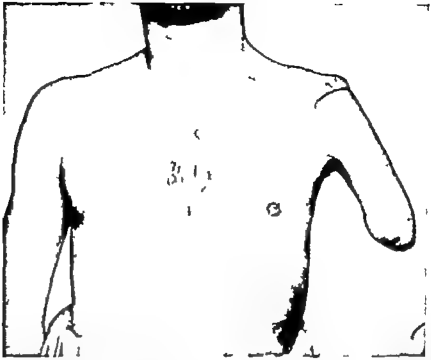
2 Kineplastic Surgery

We now pass to consider further procedures often referred to as kineplastic surgery Certain amputations e g arm and forearm amputations are wasteful because they leave highly contractile muscle bellies which although intact are ineffectual and useless from the point of view of the patient

From time to time surgeons have been stimulated to harness this wasted power The story of the development of this form of surgery is of considerable interest

During the Italo-Abyssinian campaign in 1896 among other horrible brutalities the

Fi 71 Kineplastic operation on lower end of arm The two humeral condyles have been separated and remain together with their attached muscles. (Club motor)



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[Reprinted from Ann. Roy. Coll. Surg. Engl.

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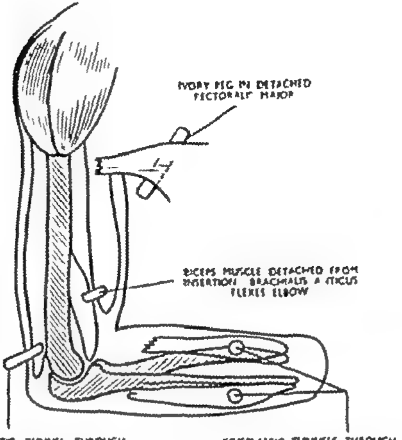

FIG. 223. Diagram showing the usual accepted sites for kineplastic tunnel
(Ann. R. Coll. Surg. Eng.)

The loop motor has been used in lower extremity amputations, e.g. below knee amputations. Apart from the technical difficulty and the absence of sufficient muscle power, this procedure is unnecessary since we have at our disposal useful artificial limbs which do not require such elaborate surgical procedures.

Kineplastic procedures have never proved popular in Britain, but there would seem to be a need to review them and to maintain an open mind on this subject (Fig. 223).

The kineplastic muscle tunnel is simple in design and construction. It is formed

Making the skin tunnel (a) Flap cut out (b) Muscle tunnelled; (c) Skin tubed; (d) Tunnel through muscle skin grafted

FIG. 224

Abyssinians cut off the hands of a large number of Italian prisoners Dr Guiliano Vanghetti, a general practitioner of Empoli in Tuscany turned his thoughts to the development of surgical procedures to relieve these victims He conceived a plan for so modifying the stump by operative measures as to enable the remaining muscles of the stump to be harnessed to a prosthesis and thus to actuate the artificial limb He had little opportunity of putting his ideas into practice but though his work was limited to experiments on fowls, his writings stimulated surgeons like Ceci and Putti in Italy and Sauerbruch in Germany to give his ideas practical shape

Kineplastic surgery uses the remaining stump muscles for motor purposes These muscle motors are of three kinds —

(1) The clava or club motor
(2) The ansa or loop motor and
(3) The canalis or tunnel motor

(1) THE CLUB MOTOR is constructed by freeing the tendinous insertions of muscles into bone or the muscle expansions on to bone together with a portion of the adjacent bone The insertion and the bone are then covered with skin When the muscle contracts

FIG 222. Kineplastic tunnels in the flexor and extensor groups of arm.

it is able to move the disconnected osseous nodule This type of motor can be attached by means of a ring and a cord which is harnessed to a prosthesis An example of this type of motor is shown in the pictures of a case of above-elbow amputation in which the antebrachial muscles form one club motor (flexor) and the extensors form another (Fig 221)

(2) THE LOOP MOTOR, described by Putti utilizes the skin subcutaneous tissue and the muscles at the end of a stump e g the forearm. It is formed into the shape of a jug handle The radius and ulna are shortened for about 3 in the interosseous membrane divided, and the neighbouring skin and subcutaneous tissue formed into a tubed skin pedicle so as to cover the tendons or muscles which are re-united A terminal loop is thus produced which consists of tendon and muscle surrounded by skin By means of a cord a prosthesis can be attached to the loop

(3) THE TUNNEL MOTOR. For this a tunnel is made through the flexor group of muscles and another through the extensor group of muscles The attachments of the muscles are then freed sufficiently to enable the muscle excursion to be increased The muscle tunnels are lined with skin from a previously prepared tubed skin pedicle (Fig 222)

For practical purposes the club motor and the loop motor have now been abandoned. The tunnel motor has been developed both physiologically and surgically into the best method. An over riding necessity for all kineplastic motors is a prosthesis with a light mechanical hand which can be harnessed to the motors

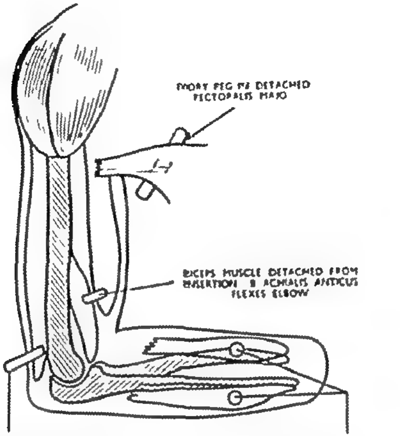

Fig 223 Diagram showing the usual accepted sites for kineplastic tunnel
(J. Bone Jt Surg.)

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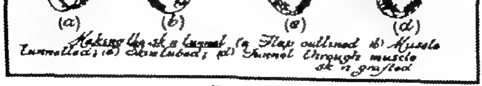

Making the skin tunnel (a) Flap outlined (b) Muscle tunnelled; (c) Skin tubed; (d) Tunnel through muscle skin grafted

Fig 224

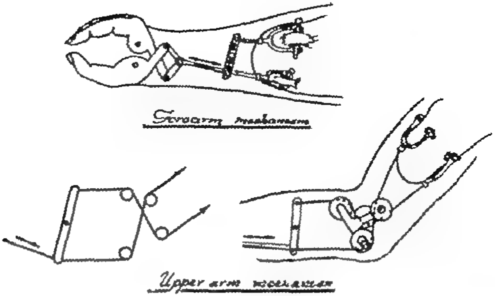

FIG 225 The principle of the mechanism of prostheses used in kineplastic stumps for both forearm and upper arm.

by the elevation of a rectangular flap of skin cut transversely to the long axis of the limb and left attached at the medial or lateral side to maintain nutrition The upper and lower edges of the skin flap are approximated and sutured to form a skin lined tube The tube is reflected transversely from its free end to expose the underlying muscle The distal portion of the muscle is isolated and its insertion severed A tunnel is made through the muscle belly just proximal to its tendinous portion and so placed that between one third and one half of the muscle mass lies superficial to it The skin is

FIG 226. Kineplastic tunnel for unilateral arm amputation. Operation ill-conceived. Conventional Artificial arm supplied.

drawn through the tunnel in the muscle and is sutured to the edge of the original incision

The tissues exposed by reflecting the skin tube are covered by a split skin graft which is sutured to the periphery of the original rectangular incision and to the free edge of the buried skin tube The range of contraction is dependent upon the stiffness or elasticity of the skin and muscle (Fig 224)

This operation was extensively employed by the Germans under the stimulus of Sauerbruch I have seen a number of these cases both in this country and in America and in my opinion the degree of control of the prosthesis is impressive (Fig 225) It is of considerable value to some patients who have lost both forearms or have very short above-elbow stumps or no upper-arm stumps at all for the thoraco scapular muscles to be used as motors

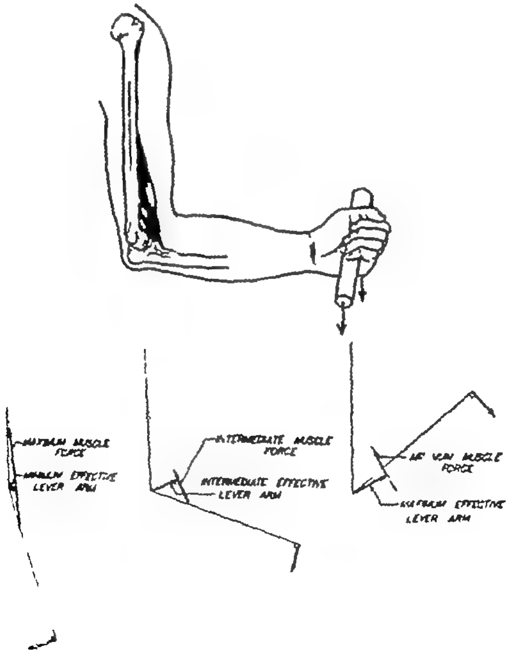

Fig 22 Variations in effective lever arm vector diagram for brachialis muscle
(Ann. Roy Coll. Surg Engl.

Dynamics of Muscle Action. The revival of interest in kineplastic surgery has stimulated work on this subject in the United States where surgeons and physiologists are studying this problem intensely The surgical placing of skin lined tunnels through the distal portions of muscles has made isolated segments of human muscles available to us for close physiological study I am grateful, particularly to my colleagues of the University of California, who gave me full access to their studies on these isolated human muscle bellies

Let us consider some of the physical points concerned with this

The human limb represents a system of articulated levers moved by muscles. Almost without exception the effective upper lever is short and the distal resistance lever is long i e the excursion of the muscle is short compared with the length of the resistance lever arm (Fig 227)

The pull of the muscle—the power of the machine—is close to the fulcrum of the lever The demands on muscle power are therefore considerable particularly when the distal lever arm is loaded Such a mechanical arrangement would at first sight appear to be ill planned but in fact it ensures speed of action and a wide range of movement Muscle tone contributes to this effect for a muscle unless cut through or completely isolated, is always in a state of partial contraction hence it can act without delay since there is no slack to take up

A muscle in order to achieve a wide range of movement has no need to start from a state of complete relaxation but can adjust its range by virtue of minute alterations in the fibre length itself The absolute amount by which muscle can be passively stretched and actively contracted depends upon the length of the individual muscle fibres. The longer the muscle the longer the fibre and the greater the power The corollary follows that the optimal length of the individual muscle fibre will depend on the excursions of the skeletal elements

Specialists in kinetization seem to prefer to use muscles with parallel fibres, for these fibres give maximum shortening But power—while in some degree related to this shortening—depends far more upon the *area* the fibres occupy in a section made at right angles to their length

In practice however tunnels must often pass through a mixture of parallel and pennate fibres and though some of the pull of a pennate muscle crosses the line of its tendon and so reduces excursion, pennate muscles often subserve movements that require habitual strength and the obliquity of their fibres lessens the risk of rupture when their tendons are strained It is wise therefore when amputating with a view to kineplasty to spare as great a length as possible of skin and muscle belly—whether the muscle fibres are parallel or pennate In these respects we must revise our present attitude towards the fixing of elective sites for amputation in the upper limb

Observations on the Excursion of Contracting Muscle. According to Weber within one muscle the length of the individual muscle fibre is approximately the same and the fibres in the human muscle system vary in length and may be as much as 4 or 5 cm Haines estimated that when a muscle in which the fibres are running parallel contracts it is shortened to 57 per cent of the stretched length In pennate muscle the excursion is less

The kineplastic muscle tunnels have given us exceptional opportunities for the study of the dynamic laws of isolated human muscle-bellies For the first time it has

been possible to study such action under the stimulus of direct volition in contrast with the artificial stimuli used in animal experiments

Such kineplastic limbs have been subjected to intensive study in which electromyography has proved a valuable aid The varying forces in different states of muscle contraction have been determined by means of the dynamometer using aluminium rings and strain gauges It has been shown that there were two types of muscle action confirming the experimental work of physiologists first the isometric type not permitting appreciable shortening to occur and second the isotonic type in which shortening is permitted

In kineplastic amputees both types of contraction are necessary to activate a prosthetic device When the shape of muscle is transformed from the longitudinal to the transverse axis the length decreases while its girth increases and its power decreases Let us compare the data derived from the kineplastic muscle tunnels with the maximum theoretical excursion

TABLE I

Muscle	Average length (inches).	Maximum theoretical excursion (0 5 × length in inches).	Average experimental values (from kineplastic tunnels) (inches).
Biceps brachii	5 1	2 0	2 5
Brachialis	3 5	2·0	—
Triceps brachii	7 1	1 8	1 7
Deltoid	3·6	2·0	—
Pectoralis major	6·0	3·4	4 3
Trapezius	4 3	2·4	—
Latissimus dorsi	8·0	4·6	—
Average of flexors of forearm	2 5	1·4	1·0
Average of extensors of forearm	2·4	1·4	0 7

It will be noted from Table I that with the exception of the pectoralis major the theoretical excursion was not attained in the muscles having tunnels although the two values are reasonably close The excursion of the pectoralis major exceeds the theoretical figure because the muscle can be stretched more than others and still return to a normal contracted length

Obviously it is desirable to harness the maximum power to activate the prosthesis and in order to assist the amputee force multipliers have been constructed A force multiplier is a mechanism which produces no change in the reaction force or in the length of the pulling cables until a pre-determined pull is reached It then begins to act as a simple lever which increases the force and enhances the available muscle power

From these studies it is seen that kineplastic muscle tunnels may serve a useful function in moving an artificial hand actively voluntarily and in a manner approaching the function of the natural limb

Clinically kinetization in upper-extremity amputations has definite and important advantages The prosthesis seems to become a part of the patient He readily appreciates that with a will to strive success will come and he joins eagerly in response to the enthusiasm of the surgeon In the fitting of all such activated upper arm protheses

the attitude of the patient is an important consideration It is no mere cliché to say that the prosthesis should snugly fit the mind as well as the stump

If this operation has value why has it not been universally employed ? There are several reasons —

(1) Plastic tunnels are not as easy to prepare as the diagrams indicate They were tried out after the First World War but the skin became excoriated and broke down.

FIG 228. Patient using his artificial hands.

They were thus rendered incapable of further use but plastic surgery has made great strides since then and in skilled hands this is not an obstacle to-day

(2) Whilst great strides have been made in the improvement of the kineplastic prosthesis the lack of a perfected model is still one of the great obstacles

(3) Amputations in the past have often been performed without taking into consideration the possibility of utilizing the remaining muscle-bellies stumps have thus been rendered unsuitable for kinetization.

(4) A large number of amputations went septic in World War I, with great muscle destruction and consequent fixation In the last war owing to the advances in chemotherapy, sepsis was not a major factor

(5) I am of the opinion that there is as yet no comparable alternative to kinetization

for the very short arm amputation case As we shall see later however there is now being developed in this country a useful artificial hand activated by the shoulder muscles but this is for below-elbow amputations (Fig 228)

3 The Krukenberg Operation

Kineplastic surgery *per se* can only give the faculty of prehension and not that of tactile sensibility

The object of the Krukenberg operation is to convert the radius and ulna into the two jaws of a "crocodile" forceps with tactile sensibility (Fig. 229)

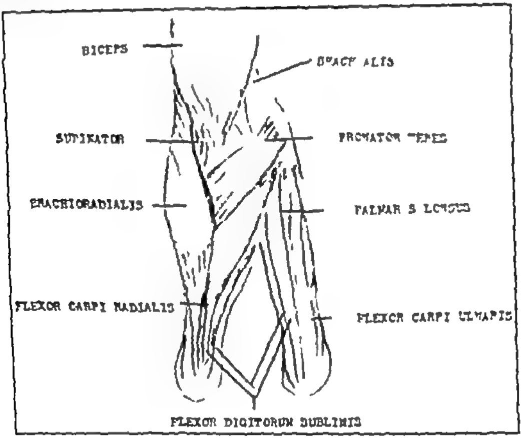

FIG 229 Diagram showing the distribution of the muscles of the forearm in a Krukenberg operation

[J a. Roy Coll. Surg Engl.

The following is a description of the method —

Incision The line of incision is kept close to the ulna and begins on the volar surface of the forearm at a point 7 cm distal to the bend of the elbow Thence it passes longitudinally and turns round the end of the stump to a point at the same level on the dorsal surface This gives a "U"-shaped cut which is deepened so as to separate the flexor digitorum sublimis into a radial and ulnar moiety

Resection of Nerves and Muscles. The median and ulnar nerves are cut short taking care not to damage branches which pass to useful muscles The flexor pollicis longus and the flexor digitorum profundus are entirely resected in order to make the two jaws of the forceps less bulky and easier to clothe with skin.

Division of the Interosseous Membrane This membrane is divided for a distance sufficient to obtain a separation of 12 cm between the ends of the radius and ulna In

FIG 230 Krukenberg operation on long forearm stump.

making this cut the knife should be kept close to the ulna and the interosseous arteries should if possible be spared

Treatment of the Bones and Remaining Muscles. The radial moiety of the flexor sublimis is sutured to the flexor carpi radialis and the ulnar moiety to the ulnar flexors The extensors are similarly divided into radial and ulnar groups The extremities of the radius and ulna are freshened by removing a centimetre of bone from each shaft and their ends are grooved The radial flexors are joined with the radial extensors in such a

FIG 231 Bilateral Krukenberg claw writing
[Ann. Roy Coll. Surg Engl.

way that the junction between them lies in the groove at the end of the radius the ulnar flexors and extensors are similarly dealt with (Fig 230)

Skin Closure Owing to the ulnar position of the skin incision closure is easily effected round the radial jaw of the forceps A raw area remains on the ulnar part and this is grafted either at once or later after temporary Thiersch covering by means of a pedicled flap cut from the abdomen

Movements are begun as soon as healing is complete and are supplemented by the usual routine of massage and electrical treatment

Abduction of the radial limb of the forceps is produced by the brachio-radialis muscle and the extensor carpi radialis while adduction is produced by the pronator teres flexor carpi radialis and half of the flexor digitorum sublimis

There have been many objections to the operation Let us therefore consider them

First the stump is considered by some to be unsightly (Fig 231) After the First World War a British soldier was subjected to the operation whilst a prisoner of war in Germany When he returned to this country his case was reported in the newspapers as an example of German atrocities on prisoners of war It should be remembered that medical men regard anatomical anomalies differently from the general public I have spoken to patients who have disliked the appearance of the Krukenberg arm (Fig 232)

On this point should we not consider first last and all the time the patient s reaction rather than our own surgical enthusiasms ? At present there is no indication that people

FIG 232 Bilateral Krukenberg claw turning over pages of a book.

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in this country would accept this procedure, those to whom it has been offered have refused

The second objection that the Krukenberg precludes the wearing of an artificial limb can no longer be held valid, for any of the standard prostheses can without difficulty be fitted to a Krukenberg stump

The third objection that a man with a forearm stump is capable of doing more with a prosthesis than with a Krukenberg stump may be true but it should be remembered that comparisons depend upon the skill with which the patient uses either his Krukenberg

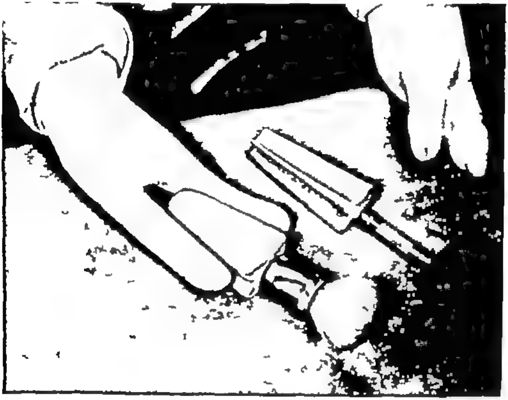

Fig 233. Bilateral Krukenberg "claw" showing method employed for toilet.
(Ann. Roy Coll. Surg. Engl.

or his artificial prosthesis, and again it must be borne in mind that the type of employment is important (Fig 233)

The Krukenberg patient learns to use his forearm prongs as easily as the ordinary patient learns to use a prosthesis but facility will always depend on the diligence with which either patient applies himself to the task.

There are two advantages of the Krukenberg procedure —

(1) The patient is spared the trouble of putting on an apparatus and he retains tactile sensation. The retention of sensation is of inestimable value in the case of the blind The Krukenberg would thus seem to be indicated for blind double arm amputees (Fig 234)

(2) The Krukenberg operation has a definite place in amputations performed on people in remote regions where there are no facilities for prosthetic appliances and where their only alternative is a useless stump These people may not be able to afford a

Fig 234 Some appliances used in bench work

prosthetic appliance and if in possession of one may not be able to keep it in good repair

4 **Methods of Making the Forearm Prehensile by Enlisting Pronation**

(*a*) **Putti's Method** Putti relates how Dalisch a German in 1877 took out a patent for a leverage whereby pronation of the forearm stump could close an artificial hand whilst supination opened it He noticed too that Pedrazzoli and Spitzy each indepen dently (in 1910) had likewise harnessed these movements In two of Putti s patients with long forearm stumps—refashioned so that they could activate a hand of this mechanical variety—there came a windfall both men when they removed their artificial limbs were able (by rotation of the radius) to *grasp* and *feel* what they were grasping They wrote without prosthesis and one who was completely blind read Braille by touch of his prehensile forearm Krukenberg who published his method in 1917 must have been working on it near the time that Spitzy and Pedrazzoli were engaged on theirs Each of these three surgeons divided radius from ulna and covered the bone with skin But while the Spitzy Pedrazzoli separation of the bones was restricted to the distal end of the stump and was designed to activate an artificial hand Krukenberg s division as we have seen extended much further up the forearm which it made self sufficient

(*b*) **A. K Henry's Method.** This was worked out independently without knowledge of Putti s method or of Krukenberg s (*Brit Journ of Surgery* 1928 Vol 16 p 188) It supplies the forearm with a stiff digit which active pronation brings into strong opposition

with a simple prosthesis The skeleton of the digit is formed by separating a rod from the lateral side of the lower end of the radius The rod is set at an angle with the radial shaft and its base which remains attached by periosteum subsequently fuses with the shaft The digit is clothed with skin and provided with muscle the trunk of the radial artery supplies it Muscles are attached as follows to the end of the dorsal aspect of the rod are fixed the dorsal tendons of the thumb the tendon of brachio-radialis, and the tendons of the radial wrist extensors The tendons of flexor carpi radialis and of flexor pollicis longus are attached to the palmar aspect of the tip

An attempt was made in the first case to provide a joint half way down the rod, but ankylosis occurred thus leaving a rigid, sentient digit which could be opposed by pronation to a prosthesis consisting of a forearm gauntlet fastened—in order to prevent rotation—to a leather arm cuff by means of two metal bands hinged at the elbow one on either side

Two patients were treated in this way but in the second no attempt was made to form a joint in the new digit Both patients had highly skilled use of their reconstructed forearms One a boy was able to continue his work at tooling patterns in brass The other an adult was observed for nine years after operation and the force exerted by the new digit was quite remarkable his grasp on an observer s finger became unbearable

It had been Henry's intention to provide a second living digit from the ulna, so as to render a prosthesis unnecessary but the occasion did not present

W S Somerville-Large of Dublin carried out this further procedure with complete success in 1931 on a case which he demonstrated before the Dublin Biological Society

5 Neo-arthrosis of the Shaft of the Humerus

Operation of Neo-arthrosis of the Shaft of the Humerus. This operation has value in amputations of the upper limb when the function of the elbow joint is lost

The loss of an arm in a manual worker is obviously much more serious than the loss of a leg but it is doubly serious when the elbow joint is lost as the natural movements performed at that joint are very imperfectly and very inadequately accomplished even by the best prosthesis and then only with considerable difficulty Preservation of the elbow joint *or its replacement by an equivalent articulation is therefore greatly to be desired*

A school master both of whose hands had been amputated when he was six years old, had learned to be absolutely independent and had passed his examination entitling him to a Teacher s Certificate Without an artificial limb he could dress himself shave eat with grace and assurance write an unusually legible hand with more than average rapidity travel long distances alone and pay his fares just like a normal individual. All this in virtue of the fact that he still had both his elbow joints intact

So much has the importance of the elbow joint been impressed upon us at Roehampton that every endeavour is made to save at least a few inches of the forearm. The limb makers with the close and active co-operation of the limb-fitting surgeons have with patience and ingenuity succeeded in producing a limb that can be fitted to an extremely short forearm stump even one as short as 1½ in. (3 cm) below the insertion of the biceps tendon

There remains however a residuum of cases in which either because of the site of

the original injury or disease or because of sepsis it is necessary to amputate at a level that involves the loss either functional or anatomical of the all important elbow joint (Fig 235)

Hitherto it has been the custom in such cases to amputate at the so-called site of election which frequently involves the loss of healthy skin muscle and bone It was this loss of sound tissues that first made me wonder whether some use could not be made of them The idea was thus conceived of constructing a simple joint in the shaft of the

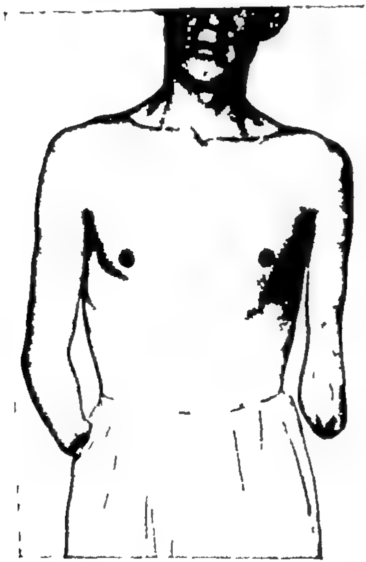

Fig 235 Severe electrical burns involving both hands and forearm with loss of skin on the left forearm stump and a stiff elbow joint Arthroplasty of left elbow

humerus at the site of election for amputation with a short distal stump that could be made to function as a forearm controlled by the powerful flexor and extensor muscles that normally control the movements of the natural forearm

So far as one could see nothing could be lost by this procedure except time and if the newly created joint proved a failure the joint having been made at the site of election re-amputation could still be carried out without any greater loss of tissue than would have been the case had the usual amputation been undertaken in the first instance My

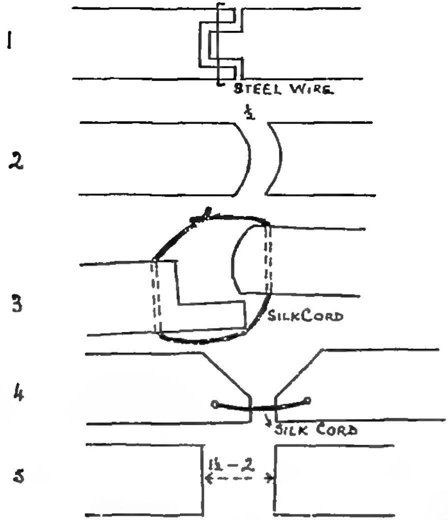

Fig 236. Illustrations 1–5 showing the stages through which the operation has progressed to date.
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Fig 237

Fig 238.

Fig 239

Neoarthrosis of the humerus showing range of movement
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FIG. 240. Neoarthrosis of lower third of humerus. Bony spurs growing from adjacent end. Metallic foreign bodies present

FIG. 241. Neoarthrosis of the shaft of the humerus. Wearing a prosthesis.

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FIG. 242. X ray showing the range of movement which is able to be accomplished in a neoarthrosis of the humerus.

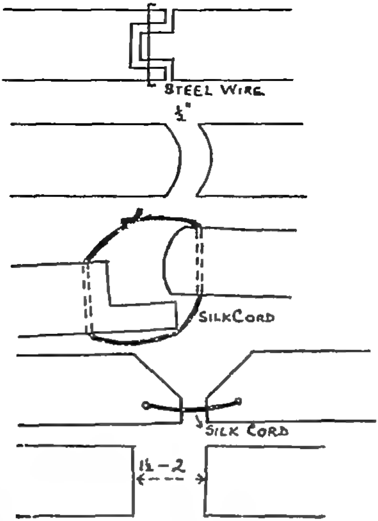

FIG 236 Illustrations 1–5 showing the stages through which the operation has progressed to date.
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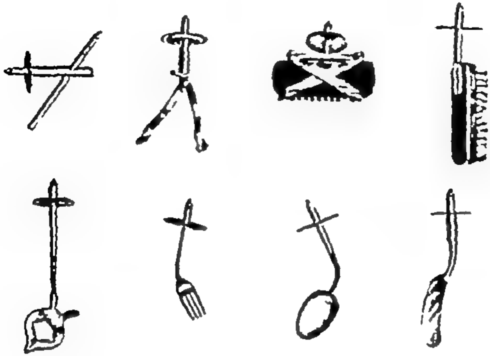
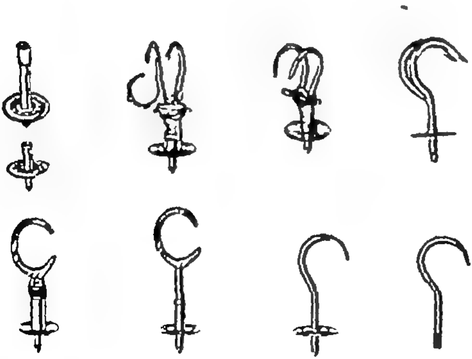
FIG. 237 FIG 238. FIG 239
Neoarthrosis of the humerus showing range of movement
[Ann. roy Coll. Surg. Engl.



A selection of household and toilet appliances which can be plugged in.



Selection of tools which can be plugged in to the forearm rotary mechanism as required.

FIG 245

(a)

FIG 243 Neoarthrosis of the shaft of the humerus (painless and powerful movement)

(b)

Neoarthrosis of the shaft of the humerus, showing the power which can be attained.

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FIG 244. Neoarthrosis of the left arm. Able to lift quite heavy loads painlessly

Fig. 246 R. Amputation of hand and part of forearm. Artificial hand supplied L. Amputation of forearm and hand Nearthrosis of the arm. Artificial hand supplied.

efforts however to produce a satisfactory new joint were at first foiled by the formation of exuberant callus and the subsequent ankylosis of the false joint

Several methods (shown in order of adoption in Fig 236) were tried It was found that fashioning a replica of a joint failed because of the rapidity with which the bone threw out callus and caused fixation despite the fact that —

(1) The bone was divided more or less transversely at a point usually considered common for non union and

(2) Movements were begun within a few days after the operation

Finally however the following methods were evolved and have proved to be satisfactory —

(1) The resection extra periosteally of 1½ to 2 in (4–5 cm) of the shaft of the humerus at the proposed site of the new joint After this burning of the bone ends by electrocautery was regularly performed to ensure non union

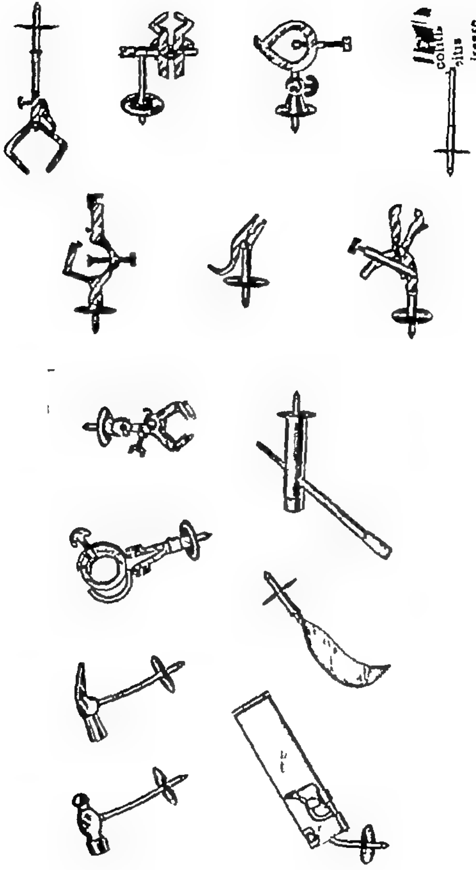
I subsequently learned it was over one hundred years ago that Charles Bell said —

> Scrape a bone and its vessels bleed ; cut a bone and its granulations sprout up ; break a bone and it will heal ; cut a piece away and more bone will readily be produced burn it and it dies

(2) I packed the resulting cavity with 10 to 15 gr sulphanilamide powder as an additional attempt to prevent union Sulphanilamide in high concentrations inhibits phosphatase activity

(3) Immobilisation of the arm in a straight plaster cast for two weeks at least and reduction of muscle activity to a minimum

The plaster cast being removed in about fourteen days and active movements begun



A selection of tools which are useful for certain specific occupations and can be plugged into the apparatus.

FIG 246.

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(a) (b)

Fig 247 Patient using two artificial hands. The R below-elbow and the L. neoarthrosis of the humerus. He is able to accomplish movements with dexterity and is able to grade the power of his grasp according to the requirements.

the patient readily achieves a range of 90° of flexion at the new elbow joint and this it will be appreciated, is an extremely valuable range of movement especially in double-arm amputees (Figs 237–41)

Movement of the new elbow joint fitted with a prosthesis which is a very comfortable apparatus should be noted. Note also the lessened arc of flexion and its obvious value (Fig 247*b*) The patient soon develops a powerful controlled elbow flexion which he can utilize for carpentry or any other ordinary work (Figs 242–47)

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CHAPTER XII

SOME SURGICAL PROCEDURES CONNECTED WITH AMPUTATIONS

It is vain to speak of cures or think of remedies until such time as we have considered of the causes

GALEN

Amputation of an Arm and Dissection of the Axillary Glands for a Malignant Growth of the Upper Extremity

A FORMAL amputation is first performed. With the stump held in abduction a curved incision is made convex laterally which stretches downwards from below the middle of the clavicle towards the middle of the axilla and then curving downwards for about 6 in. The incision is deepened in order to expose the pectoralis major muscle near its origin and its sternal and clavicular parts are separated. In the groove between these two parts of the muscle the thoraco-acromial vessels are clamped as they pierce the costo-coracoid membrane. The forefinger is now passed under the tendon of the sternal portion and it is divided as near as possible to its humeral insertion. The pectoralis minor muscle is thus exposed and it, too, is divided near to the coracoid process. When the pectoral muscles are retracted medially the axilla is opened. By gauze dissection the axillary vein is cleared of fat, fascia and lymphatic glands from the apex of the axilla downwards so that its anterior, medial and lateral surfaces are completely exposed. The lateral thoracic and alar vessels are divided and the intercosto-brachial nerve is seen passing across the floor of the axilla. The posterior wall of the axilla is then cleared. All visible fat and fascia are stripped from the subscapular vessels. The medial wall of the axilla is cleared and special care is taken to preserve the long thoracic nerve. The dissection is continued backwards as far as the line of the thoraco-dorsal nerve and this, too, is avoided. After all bleeding vessels have been attended to, the wound is closed in layers. A long rubber drain is inserted at its lower end.

Amputation of a Leg and Dissection of the Inguinal Glands for a Malignant Growth of the Lower Extremity

A formal amputation is performed. Then a 5 in. (12.5-cm.) linear incision is made obliquely in the groin with its centre over the femoral sheath and 1½ in. (3.75 cm.) from the pubic tubercle. With diathermy the skin flaps, superficial fascia and fat are fully dissected up and retracted and the long saphenous vein is isolated, tied and cut close to the cribriform fascia. Hæmostasis is ensured with coagulation and ligature. The saphenous opening is defined and by scissor dissection its edges are extended to the margins of the reflected flaps. Thus the mass of tissue is peeled off proximally and the femoral sheath defined. This is cleared of fascia and glands which were left incorporated in the retracted tissue block which, together with fatty tissue from the region of Cloquet's gland, is finally detached superiorly at the level of the inguinal ligament. A drain is inserted, deep catgut sutures are used to obliterate dead space and the wound is closed

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For Flexion Contractures of the Hip

Osteotomies are preferably performed above the lesser trochanter. A 6 in. (15 cm.) incision is made on the lateral aspect of the upper end of the femur. The osteotome is driven in above the lesser trochanter, parallel with the lower border of the neck of the femur. When it has reached the inner side of the shaft there may still be no appreciable movement in spite of the division of the bone. This is because the fibres of the psoas muscle act as a splint. The stump is then rotated with a torsional strain, and it will be found that the two ends are then separated. The necessary adjustments to correct the deformity are then made and, when completed, the stump and pelvis are put in a plaster spica in the corrected position. After about six weeks in plaster the patient is fitted with a plaster pylon, which not only further maintains the corrected position but enables him to mobilize his hip-joint and to begin walking. This hastens union in the corrected position.

Sinus in the Stump which is Interfering with Limb-wearing

Such a sinus can interfere with limb wearing because the constant discharge makes it unpleasant, or the irregular skin edges at the mouth of the sinus are constantly rubbed by the apparatus. To cure the condition the skin of the lips of the sinus is turned up as flaps. The fibrous tissue and granulations are scraped out of the cavity, which is extended in every direction wherever there is a channel. Any sequestra and the thinner overhanging roof of bone are then removed. In the tibia the latter may be on the medial side. A flap of muscle and soft tissue is next turned in from the adjacent muscle and the skin sutured over it. The cavity should, of course, be drained and local and systemic antibiotics should be given.

Excision of Scapula

This formidable procedure, which necessitates the division of many large muscle bellies, was described over a century ago, before the days of anaesthesia, blood transfusion and chemotherapy. Although rarely seen to-day, the operation for partial excision of the scapula was first described by William Fergusson in 1848. Complete excision was devised in 1850 by von Langenbeck.

The indications for excision of the scapula follow closely those for amputation.

Indications

1. **Trauma.** Partial excision may be required after trauma, and in severe cases of disorganization of the shoulder joint from injury, the glenoid, sometimes together with the head of the humerus, may also need excision.

2. **Neoplasm.** Complete excision of the scapula *per se* is indicated in tumours arising from that bone, and it is here that the operation is most frequently described. The tumours may be benign or malignant. In excising the bone for a benign tumour it is of great advantage to leave the acromion process, for the attachment of the deltoid and trapezius to this process will result in a much better functional result.

OPERATIVE TECHNIQUE. Von Langenbeck's original method was later modified by Watson Cheyne (1894), who recommended ligation of the subscapular vessels as the first step in the operation.

With the patient lying on his back, an incision is made in the line of the axillary artery and with its centre over the tip of the coracoid process. The cephalic vein is defined and preserved. The biceps and coracobrachialis attachments to the tip of the

after final hæmostasis with interrupted silkworm gut : Examination of the excised glands shows microscopic neoplastic involvement in 20 per cent of both superficial and deep inguinal lymph glands

Epiphysiodesis for the Prevention of Conical Stumps

A short vertical incision is made over the antero medial surface of the upper tibia This is deepened down to the periosteum which in a child is thick and adherent The periosteum is incised and separated from the bone and a cube ¾ in (2 cm.) overall is removed to include the epi physeal line Further portions of the epiphyseal cartilage are then removed with rongeurs and the cube is replaced upside down It is important to perform the same procedure over the lateral end of the tibial epiphysis, otherwise a bowed stump deformity results which is difficult to fit with an artificial limb (Fig 248) The skin is sutured with silkworm gut.

Fig 248 Below knee amputation in a child with epiphyseodesis on the medial side only Result genu varum and *difficulty in wearing his artificial limb* Corrected by osteotomy

For Flexion Contractures of the Knee

Through a posterior longitudinal incision a capsulotomy can be performed from the back All the tight posterior capsular tissues are divided right down to the joint At the same time the biceps femoris should be divided because it is one of the chief muscles which produce and maintain the deformity and it is of little value in a below knee stump The semi membranosus and semi tendinosus should be preserved if possible but if the deformity cannot be corrected, it is permissible to divide them As much correction as possible should be achieved after the operation The leg can then be put up in a wedge plaster if necessary or a spring straightening plaster can be applied. In all these cases pre-operative and post-operative quadriceps exercises should be taught at a very early date By these methods one can sometimes save the below knee amputation and successfully fit it with a prosthesis so rendering unnecessary an above-knee amputation.

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both motor and sensory fibres and consequently section of these nerves results in motor as well as sensory paralysis

In amputation stumps this procedure is limited to purely sensory nerves or to mixed nerves supplying muscles which are not essential to limb function Painful neuromas can be resected or neurectomy performed proximal to the neuroma

Before operation the likely effect of any such nerve section can be judged by blocking the nerve with a local anaesthetic

This operation neurectomy is of value in many cases that have not responded to conservative treatment A tender neuroma may be palpable at the end of the stump Pressure on this sets off not only pain but quite often phantom pains Apart from pain, some of these cases are unable to tolerate limb wearing

The operation is performed proximal to the neuroma usually on the flexor surface of the limb e.g in a below knee stump in the popliteal fossa , in a below-elbow stump in the cubital fossa and in an above-elbow stump in the axilla

These sites are relatively free from pressure A longitudinal incision should always be employed because it is less likely to cause a contracture or to interfere with subsequent limb wearing The nerve which is associated with the painful neuroma should be isolated and a segment never less than 1 in (2 5 cm) should be resected

The operation does not give uniformly good results but it is a method which does offer relief in a number of cases in which conservative methods have been of no avail

2 **Section of Sympathetic Pathways—Sympathectomy** Sympathectomy plays an important part in the treatment of painful stumps and causalgia In my experience sympathectomy either pre ganglionic or post ganglionic may relieve pain in some painful stumps in which peripheral neurectomy has been ineffective

An indication as to whether sympathectomy may prove effective can be obtained by injecting procaine into the appropriate sympathetic ganglia Sometimes such injections are not only of diagnostic but also of therapeutic value

Objects of Sympathectomy

The objects of operations on the autonomic nervous system are threefold —

(1) To abolish or diminish spasm in the vessel walls by destruction of the vaso-constrictor mechanism thus opening up the vessels and improving the blood supply

(2) To improve the circulation to an area which has had its blood supply interfered with by opening up the collateral channels The latter object is based on the assumption that these collateral vessels are themselves patent not thrombosed or too grossly altered in structure

(3) To relieve pain This is often dramatic after a sympathectomy and it has been attributed to the increased blood supply to the affected part It should however not be forgotten that after the somatic nerves to a stump have all been divided patients still complain of pain and dramatic results are then achieved by sympathectomy probably because sensory fibres are divided this being the only other available route whereby pain impulses can be transmitted centrally Lastly it should always be remembered that the immediate effect of sympathectomy is likely to be reduced by the quick return of tone in the muscle of the arterial walls In the case of disease of a limb or a stump or of pain in that stump operations depend for their success mainly upon provision of alternative channels We should be guarded in our prognosis because we

coracoid are divided These may be sutured later to the clavicle to give further post-operative stability to the shoulder joint The axillary artery is cleared and defined, and at the lower border of the pectoralis minor the subscapular artery is identified ligated and divided Great care is needed here because of the close proximity of the artery vein and nerves

The patient is now turned on his sound side to expose the posterior aspect of the scapula Two incisions are made—a curved incision along the line of the acromion to the vertebral border and a vertical incision along the medial border from the inferior to the superior angle Some modification of these incisions may be necessary to include any skin which may be involved The skin flaps are then dissected. This will give a triangular area with the deltoid laterally and ascending fibres of the trapezius medially When dealing with malignant disease the muscle attachments are divided, but for benign conditions the muscle attachments and periosteum are left *in situ* The next procedure is the division of the muscle attachments to allow removal of the different bones The order of division varies with different authors Kocher began by dissecting the lateral portion and the attachments to the humerus while Watson Cheyne advocated beginning on the medial side and later removing the humeral attachments The scapular spine is cleared of deltoid and trapezius the branches of the acromio-thoracic axis being secured at the same time The rhomboids levator scapulæ and the serratus anterior are divided along the vertebral border and the posterior scapular vessels are ligated The omohyoid and remaining fibres of the deltoid and the suprascapular vessels can then be divided at the upper part of the bone The inferior angle is next cleared by division of latissimus dorsi and the remaining bundles of the serratus anterior The acromion process is then divided or if the whole bone is being removed the acromio-clavicular joint is opened. The subscapular vessels having been secured, the axillary border can be easily dealt with If the glenoid is to be retained the rotator muscles are divided if, however the glenoid is to be excised as well then it is probably better to divide the muscle attachments at their insertion to the humerus—the supraspinatus infraspinatus and teres minor from the greater tuberosity and the subscapularis from the lesser together with the insertions of latissimus dorsi and teres major from the inner aspect of the bicipital groove Care is needed here to preserve the circumflex nerve and the posterior circumflex artery The latter however may be ligated at the lower border of the teres minor The scapula can now be easily removed by disarticulation from the shoulder joint Any remaining bleeding points may be secured and enlarged axillary nodes removed

It has been suggested that a fixed point for the head of the humerus may be fashioned by suturing the capsule and available stumps of tendons to the clavicle The upper border of the deltoid is sutured to the trapezius and adjacent muscles and should result in a fair degree of movement Post-operatively the arm is best placed upon a right-angled abduction frame

Despite the number of large muscle attachments that have been divided, the functional result is surprisingly good The prognosis in the malignant disease is also fairly favourable A tumour is often noticed early and complete excision may give the patient many years of life

Operative Procedures for the Relief of Pain arising in Stumps

1 **Section of Somatic Nerves—Peripheral Neurectomy** Most somatic nerves contain

at one sitting with the patient lying on his back This however causes post-operative shock distension which may give rise to ileus and occasionally an internal hernia into the retroperitoneal space The extraperitoneal route is simpler It gives good access but it has the disadvantage that in a bilateral operation two incisions are necessary and this therefore takes longer Shock is less but post-operative distension does occur On the whole the extraperitoneal approach is to be recommended It is safer and easier and surgical access is better

THE TRANSPERITONEAL APPROACH With the bladder empty and a general anæsthetic reinforced by curare a para medial incision is made to the left of the umbilicus The cæcum and ascending colon are retracted medially and packed off and the posterior peritoneum is incised on the outer side of the descending colon The psoas muscle is located in the extraperitoneal fat and the peritoneum together with the ureter and the spermatic or ovarian vessels are retracted with the peritoneum The genito femoral nerve is seen piercing the psoas muscle It is the only nerve which pierces that muscle The inferior vena cava comes into view and on its lateral border the sympathetic chain with its ganglia can be palpated on the side of the vertebral column just medial to the medial border of the psoas muscle The lumbar vessels which come off segmentally can be seen passing either behind or in front of the sympathetic chain

The chain should be identified with certainty this is not always easy because enlarged lymphatic channels and glands may be present especially if there has been an infective disease of the lower extremity The trunk is then lifted up with a blunt hook and two or sometimes three ganglia are identified I do not believe it is important to say that the second third and fourth lumbar ganglia are removed but it is much more important to resect about an inch of the trunk at least The operation on the left side is identical with that on the right, except that the aorta is now present and lies more to the front of the bodies of the vertebræ If any bleeding occurs through rupture of the lumbar vessels these can be clipped and treated by diathermy The posterior wounds in the peritoneum should be carefully sutured This is important as posterior hernia may occur The operation is difficult in a fat patient Digital retraction is best unless special deep retractors are available

THE EXTRAPERITONEAL APPROACH The patient is placed on his side An oblique incision is made starting at the tip of the last rib and carried downwards and medially as far as the lateral border of the rectus The external oblique the internal oblique and the transversus abdominis muscles are divided along the length of the incision until the extraperitoneal fat is reached The peritoneum is then carefully retracted medially until the psoas muscle is seen The operation is then carried out on lines similar to the trans peritoneal route Careful hæmostasis is essential and the wound should be sutured in layers with catgut

3 Section of Posterior Nerve Roots—Rhizotomy As a method of relieving pain posterior rhizotomy has limitations because it affects all degrees of sensation It is necessary to sever at least three successive nerve roots before any appreciable anæsthetic result can be obtained

Posterior rhizotomy to be effective cannot therefore be applied to pains which are diffuse in the stump

Resection of several roots would render a stump almost useless from the point of view of wearing a prosthesis

cannot stem the original disease which sometimes runs on unchecked by our intervention

Cervical Sympathetic Ganglionectomy and Trunk Section The anterior approach is preferable There is less shock and less pain post-operatively The patient lies on the table with a long round sandbag placed between the shoulders as high up as his neck. The arm or stump on the side upon which he is to be operated on is placed behind his back and fixed by means of the draw sheet An incision 6 in (15 cm) in length is made just above and parallel to the clavicle the medial extremity reaching as far as the insertion of the sterno mastoid muscle The skin and superficial fascia having been incised, the external jugular vein is divided between ligatures It is important to sever about half of the insertion of the sterno mastoid muscle into the clavicle The omohyoid muscle is next divided. The scalenus anterior muscle can now be seen in the depths of the wound by removing some of the areolar tissue and the fat which surrounds it Sometimes the transverse cervical artery and vein can be seen and these are divided between ligatures. The anatomical relations of these vessels which arise from the subclavian artery and vein respectively are variable The object of the operator should be to isolate and ligate the common thyreo-cervical trunk, as this gives him a good landmark to his ultimate goal. The phrenic nerve which lies on the scalenus anterior muscle should next be isolated and drawn medially with a tape Its course too is variable The scalenus anterior muscle is divided at its tendinous insertion into the first rib as this ensures very little bleeding and avoids damage to the thoracic duct and subclavian vessels The subclavian artery is defined and after ligaturing the costo-cervical artery it may be found easier to draw the subclavian trunk downwards Occasionally better access is obtained by retracting it upwards The finger can then be inserted into the depths of the wound and the cervico-dorsal spine palpated. Sibson s fascia is seen in the floor of the wound It is broken down by gentle pressure in the medial angle of the wound. The parietal pleura is now seen and it is stripped from the spine by finger and swab dissection It is best of course, not to tear it but if this does occur the operator should not be deterred A swab will occlude the opening which is not easily sutured The head of the second rib is identified, and the sympathetic trunk and stellate ganglion will be seen with its rami lying on the neck of the first rib If not blunt dissection will reveal it, and if not revealed, one should be able to palpate it Care should be taken because a vein and an artery sometimes cross it and these are easily damaged. A blunt hook can then be used to pick up the sympathetic chain which is divided below the stellate ganglion as are the white and grey rami of the first thoracic nerve Ganglionectomy is the operation of choice ensuring a successful operation, particularly if pain is the reason for the operative procedure The wound should then be closed in layers without drainage

The Posterior Approach. This is not recommended as the patient lies on the front of his thorax the wound is equally deep section of ribs causes pain and post-operative convalescence is longer

Lumbar Sympathectomy

The lumbar sympathetic chain can be approached by two routes —

(1) Transperitoneal

(2) Extraperitoneal

The transperitoneal route has the advantage that both sides can be operated on

at one sitting with the patient lying on his back This however causes post-operative shock distension which may give rise to ileus and occasionally an internal hernia into the retroperitoneal space The extraperitoneal route is simpler It gives good access but it has the disadvantage that in a bilateral operation two incisions are necessary and this therefore takes longer Shock is less but post operative distension does occur On the whole the extraperitoneal approach is to be recommended It is safer and easier and surgical access is better

The Transperitoneal Approach With the bladder empty and a general anaesthetic reinforced by curare a para medial incision is made to the left of the umbilicus The caecum and ascending colon are retracted medially and packed off and the posterior peritoneum is incised on the outer side of the descending colon The psoas muscle is located in the extraperitoneal fat and the peritoneum together with the ureter and the spermatic or ovarian vessels are retracted with the peritoneum The genito femoral nerve is seen piercing the psoas muscle It is the only nerve which pierces that muscle The inferior vena cava comes into view and on its lateral border the sympathetic chain with its ganglia can be palpated on the side of the vertebral column just medial to the medial border of the psoas muscle The lumbar vessels which come off segmentally can be seen passing either behind or in front of the sympathetic chain

The chain should be identified with certainty this is not always easy because enlarged lymphatic channels and glands may be present especially if there has been an infective disease of the lower extremity The trunk is then lifted up with a blunt hook and two or sometimes three ganglia are identified I do not believe it is important to say that the second third and fourth lumbar ganglia are removed but it is much more important to resect about an inch of the trunk at least The operation on the left side is identical with that on the right except that the aorta is now present and lies more to the front of the bodies of the vertebra If any bleeding occurs through rupture of the lumbar vessels these can be clipped and treated by diathermy The posterior wounds in the peritoneum should be carefully sutured This is important as posterior hernia may occur The operation is difficult in a fat patient Digital retraction is best unless special deep retractors are available

The Extraperitoneal Approach The patient is placed on his side An oblique incision is made starting at the tip of the last rib and carried downwards and medially as far as the lateral border of the rectus The external oblique the internal oblique and the transversus abdominis muscles are divided along the length of the incision until the extraperitoneal fat is reached The peritoneum is then carefully retracted medially until the psoas muscle is seen The operation is then carried out on lines similar to the trans peritoneal route Careful haemostasis is essential and the wound should be sutured in layers with catgut

3 **Section of Posterior Nerve Roots—Rhizotomy** As a method of relieving pain posterior rhizotomy has limitations because it affects all degrees of sensation It is necessary to sever at least three successive nerve roots before any appreciable anaesthetic result can be obtained

Posterior rhizotomy to be effective cannot therefore be applied to pains which are diffuse in the stump

Resection of several roots would render a stump almost useless from the point of view of wearing a prosthesis

Posterior rhizotomy will not relieve the pain of causalgia or of painful phantom limbs

4 **Section of the Anterolateral Column of the Spinal Cord—Anterolateral Chordotomy** This would appear to be a useful operative procedure for relieving painful stumps because it produces loss of sensation for pain and temperature only and the remaining sensory impulses, including touch and posture are preserved It is applicable to widespread pain affecting the stump and it has been tried for phantom pains and painful neuromata which have not yielded to other surgical measures Chordotomy for pain in the lower limbs when due to a focal organic lesion may give good results, provided the spino-thalamic loss extends to a sufficiently high level In painful stumps in my experience this operation does not give good results (Fig 249)

Fig 249 Incision for chordotomy for intractable pain in stump of arm.

It may be that in long-standing cases of pain there are changes at a higher level which are not well understood In testing these cases post-operatively even where loss of sensation has extended to a sufficiently high level the patients still complain of pain

The trauma produced by the socket on the insensitive stump often results in abrasions I have seen severe skin ulceration as a result of wearing an artificial limb on an above knee stump following chordotomy

Riddoch and White described their successes with anterolateral operation for painful phantoms treated for the upper limb by high cervical chordotomy

Recently the effectiveness of chordotomy in relieving phantom pain after amputation has again been recorded by White and Sweet These authors state that in their experience with more radical trans-section of the anterolateral spinal quadrant of the cord and the establishment of a high sensory level anæsthesia they failed to obtain satisfactory relief in only 3 out of 14 cases

They obtained long-standing successful results in 7 of 10 cases by this operation for painful phantoms in the lower extremity The three failures were due to persistence of painful postural sensations despite an adequate level of analgesia

Of 4 cases of painful phantoms in the upper extremity where it is exceedingly

difficult to obtain permanent analgesia in the upper cervical dermatomes there were ultimate failures in 2 cases because of late falls in the analgesic level at six months and three months respectively and, in 1 case relief was not obtained in spite of apparent analgesia to the third cervical dermatome

Complications following these chordotomies have not been frequent or serious

Falconer in a recent publication in the *British Medical Journal* reports his experience in treating 12 patients with intractable phantom limb pain 6 of whom had involvement of the upper limb and 6 of the lower limb Each patient had suffered severe pain for some considerable time mostly a matter of years and many of them had previously been treated by such measures as resection of neuromata sympathectomy or reamputation without benefit Each patient was then submitted to an anterolateral chordotomy at an appropriate level and subsequently a pronounced relief of pain was observed in 9 of them slight benefit in 1 and return of pain in the remaining 2

It has generally been found that after this operation the pain in the phantom disappears although the phantom may persist

It has been found also that posterior rhizotomy has no effect on such pain and therefore it is suggested that the structures responsible for the pain are the secondary or tertiary neurones The secondary neurones have their cell bodies in the substantia gelatinosa of Rolando and their axons ascend in the spino thalamic tract but division of the tract is not always successful because there are neurones at a still higher level in the central nervous system which are presumably perpetuating the pain

Case Report II *R B., aged* 37

1942 Gun shot wound right knee

High above knee amputation (right) by Japanese Thereafter painful stump

(a) 1945 *Right lumbar sympathectomy* (Aldershot)
Temporary relief pains two weeks

(b) 1947 *Division right sciatic and femoral nerves*
Temporary relief at best or no relief

(c) 1948 (March) *Chordotomy (left)* D.3 (4 0 mm)
Anæsthetic stump and pain free till about February 1950. Pain gripping as if stump was in a vice Profuse sweating disturbed sleep

(d) 1951 (July) *Chordotomy (left)* D 1 (5·0 mm.)
Satisfactory result When last seen admitted to being free of pain.

5 **Posterior Chordotomy** Pool (1940) and also Browder and Gallagher (1946, 1948) who worked independently investigated the effect of section of the posterior column of the spinal cord They assumed that if the proprio-ceptive pathways from the whole limb were severed the cramped posture of the phantom limb might be relieved Then the pain and even the phantom itself might disappear Pool operated on 3 cases of phantoms of upper limbs dividing the lateral part of the posterior column at the level of the fifth cervical lamina He found that in at least 1 patient under local analgesia the pain was not relieved until the incision had been carried laterally across the line of the posterior nerve roots and into the substantia gelatinosa of Rolando The 3 patients seemed benefited and in each diminished sensibility to pinprick together with an exaggerated response to temperature was observed over the upper thoracic segments

Posterior rhizotomy will not relieve the pain of causalgia or of painful phantom limbs

4 **Section of the Anterolateral Column of the Spinal Cord—Anterolateral Chordotomy** *This would appear to be a useful operative procedure for relieving painful stumps because* it produces loss of sensation for pain and temperature only, and the remaining sensory impulses including touch and posture are preserved It is applicable to widespread pain affecting the stump and it has been tried for phantom pains and painful neuromata which have not yielded to other surgical measures Chordotomy for pain in the lower limbs when due to a *focal organic lesion* may give good results provided the spino-thalamic loss extends to a sufficiently high level In painful stumps, in my experience this operation does not give good results (Fig 249)

Fig 249 Incision for chordotomy for intractable pain in stump of arm.

It may be that in long-standing *cases of pain there are changes* at a higher level which are not well understood In testing these cases post-operatively even where loss of sensation has extended to a sufficiently high level the patients still complain of pain

The trauma produced by the socket on the insensitive stump often results in abrasions I have seen severe skin ulceration as a result of wearing an artificial limb on an above-knee stump following chordotomy

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Of 4 cases of painful phantoms in the upper extremity where it is exceedingly

connected with the phantom enter into consciousness at least partly in this area. de Gutierrez-Mahoney in discussing his long-term findings drew attention to the second sensory cortical area described by Adrian (1940), by Woolsey and Fairman (1946) and by Penfield and Rasmussen (1950) which is situated along the upper bank of the Sylvian fissure in the parietal region and which receives sensory impulses from both sides of the body. It would seem possible that the return of pain some time after post-central gyrectomy may be due to increased functioning of this second sensory area.

Patient R. F.

1916	[illegible] wound left leg [illegible] and fracture left femur
1918	*Above knee amputation (left)*
1946	First mention of pain in the stump, gripping in character
194[illegible]	(a) *Left lumbar sympathectomy*
	(Apparently little or no relief and 1948 was taken up with numerous local injections.)
1950	(b) *Chordotomy (right) D.3 (4.5 mm.)*
(June)	(Only three weeks relief of pain.)
1950	(c) *Spinal anaesthetic*
(October)	Still complains of pain in spite of clinical anaesthetic.
	Local injections no relief.
	Spinal anaesthetic better result but still complains of pain.
1951	[illegible] *and further local injections*
(early)	Little or no relief.
1951	*Excision sensory cortex*
(November)	This is said to have given relief.
1952	Pain in stump is mentioned again.
(July)	
1952	*Neuroma crush*
(Aug.–Sept.)	Notes state too early to assess result.

8. **Fractional Lobotomy**: (a) *Rostral Leucotomy*. This is an operation which was developed by McKissock and consists of selective cortical undercutting, but it is not very extensive and one of its objects is the relief of pain. It may be proved suitable in some cases because it is not intended for use in psychotic states where an extensive full leucotomy is the operation of choice.

The results obtained with this operation have shown a much smaller degree of change in personality than more extensive leucotomy.

Van Wagenen (1944), Watts and Freeman (1948) and Waugh, Cameron, Howarth and Matas (1940) have all reported successful results in painful phantoms after prefrontal leucotomy. Le Beau (1950) has observed benefit following topectomy.

(b) *Topectomy*. This operation is a fractional ablation of the frontal cortex; the grey matter is resected and the white matter is almost entirely spared. The amount of tissue removed is usually between 25 and 40 grm. on each side.

The relief produced by these procedures is presumably similar to that observed following these same operations for pain due to malignant disease and other organic pain-states, in that the pain persists but no longer worries the patient as formerly. Some degree of emotional blunting is probably inseparable from a beneficial response. Therefore such operations should not be tried or contemplated for painful phantom limbs until other

The explanation of these sensory changes in thorax and phantom might lie in the involvement of the secondary sensory neurones of the substantia gelatinosa The benefit in Pool s cases was not permanent

Browder and Gallagher operated on 6 cases 4 lower limb phantoms and 2 upper limb phantoms For the lower limbs they divided the whole of the dorsal column on the appropriate side at the mid thoracic level. For the upper limb they operated at the C 2 level sectioning the lateral two-thirds of the dorsal column without disturbing gait or stance Three patients after dorsal chordotomy had complete loss of the phantom foot and the cramp-like pains In the other case the pain was relieved but the phantom persisted. There was no disturbance of motor power in the stumps of 4 of these patients nor of touch, although vibration sensibility in the stump was diminished in 3 It was difficult to evaluate the results in 2 cases and neither case could be regarded as successful. Browder (1952) said, however that the benefit observed in the lower limb cases has been permanent

The rationale of these operations is difficult to understand, for the fibres in the posterior column are the proximal axons of cells in the dorsal root ganglia and yet posterior rhizotomy which severs the same axons but at another site does not relieve pain.

6 **Spinothalamic Tractotomy in the Brain Stem—Medullary Tractotomy and Mesencephalic Tractotomy** The technical difficulties of this operative procedure are great I have no experience of this form of treatment for the relief of painful upper stumps

For desperate cases of phantom arms especially after amputation near the shoulder in which technical difficulties complicate complete interruption of the secondary axons conducting pain, some form of operation on the frontal lobes may occasionally be justified, where no relief has been obtained by other methods and where mental symptoms have become established

In view of the serious mental and psychical deterioration that so often accompanies sacrifice of portions of the frontal lobes anterolateral chordotomy seems preferable as a primary operation for painful phantoms of the lower extremity where surgical procedures such as excision of neuromas division of the sciatic nerve reamputation, and sympathectomy have failed to give relief

It should always be remembered however that there may by now be advanced narcotic addiction or serious psycho-neurotic overlay

7 **Ablation of the Post-central Gyrus** In 1944 de Gutierrez Mahoney reported having successfully relieved pain in a phantom upper limb by excision of the appropriate area of the post-central gyrus of the opposite cerebral hemisphere Since then other surgeons also operating under local analgesia have confirmed that stimulation of the appropriate area, followed by electrical resection of the area, will abolish the awareness of the phantom in addition to the pain. Echols and Colclough (1947) and Stone (1950) reported their experiences shortly after operation and claimed good results but Horrax (1946 1948) and Sunderland and Kelly (1948) said that in their cases pain usually returned within a few weeks or months This has also been my experience so there is some doubt about the permanence of pain relief after this operation

The fact that stimulation of the post-central gyrus intensifies the pain while excision of the gyrus destroys the phantom as well as the pain suggests that the sensations

FIG 250 Comminuted fracture of lower end of the humerus and upper end of ulna. Disorganization of the elbow joint numerous foreign bodies present

FIG 251 An arthroplasty of this elbow with a below-elbow stump giving a good range of painless movement A prosthesis was fitted and the patient resumed his work as a sheet metal worker

measures such as percussion of neuromata and anterolateral chordotomy, have been tried and have all failed

There is a small place for anterolateral chordotomy in cases of pain in phantom limbs but I do not think there is any for spino thalamic tractotomy bilateral prefrontal leucotomy resection of the sensory cortex especially in these cases where the patient has to continue wearing artificial limbs Leucotomy for cancer is a means of making the final stages of life more tolerable and therefore the side-effects are accepted.

The following case report illustrates the uncertainty of the results of treating these difficult problems.

Case Report Mrs M S., aged 66

This patient gave a history of "brittle bones" in her right leg from birth, and from the age of two she sustained several fractures some or all of which did not unite She wore a walking caliper and a high surgical boot on this leg She has suffered pain in her right leg on and off since this time and this has become more severe since the leg was amputated. She developed Von Recklinghausen's neuro fibromatosis in childhood a condition which is manifested in several other members of her family

In 1936 she had a below knee amputation, followed in 1937 by an above knee amputation for a painful stump This gave scant relief and in that same year the sciatic nerve was divided The result was poor the pain still persisting A year later the scar was trimmed

Ten years of pain elapsed, and in 1948 she was given an intra-spinal injection of alcohol. She was incontinent of urine and fæces for three days after the injection, but control returned satisfactorily The pain was relieved only for a few days.

In 1950 a course of percussion therapy was given and there was some improvement for three months The following year the stump was re-modelled.

In 1952 a chordotomy at the level of T2 and T3 and a sympathectomy were performed, but the patient states that the pain has been much worse since this procedure

Her present complaint is :—

1 Pain at the origin of the adductor muscles from the adductor tubercle associated with spasm and a dragging sensation, and relieved by pressure on the muscle She is fairly definite and consistent about this pain, and it may have an organic basis.

2. Terrible pains, vaguely and unconvincingly described, at the sites of all her scars, i.e. stump scars, and those resulting from her sciatic nerve section, sympathectomy and chordotomy These scars are all linear extremely supple and mobile and one would not expect them to cause pain.

The distress of such a patient may be shown by the following extract from her case notes —

O/E Has auricular fibrillation, and also an advanced generalized neurofibromatosis. The papillomata are sometimes painful, and she describes how pressure on certain of these causes pain in certain areas of her stump

The stump is a good shape and is fully mobile but it is wasted and flabby

Treatment Short wave diathermy to adductors.

Postpone percussion therapy

20 1.53 Short wave diathermy to adductors has failed to produce any improvement in this area.

FIG 254 Abscess opening in front of thigh stump Broad incision marks—most practical area for drainage Thin incision where scarring is undesirable

Patient has had no children She lives in a ground floor flat and is alone all day but this does not worry her as long as she is able to get from room to room on her artificial leg She blames each successive operation for exacerbation of her symptoms, and refers nearly all her pains to her surgical scars She has a miserable appearance and her sole topic of conversation is her pain and complaint against the various surgeons who have made it worse

Treatment : Proceed with percussion

26 1.53 Percussion therapy of no real value

See Figs 250–54

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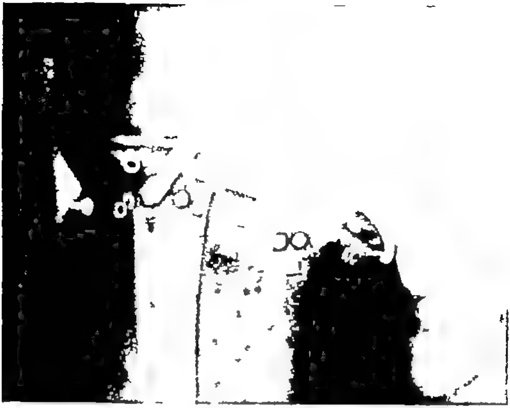

FIG 252 Above-knee amputation. Arthroplasty of the hip with replacement of the head of the femur by metallic head for osteoarthritis of the hip Wearing his artificial limb

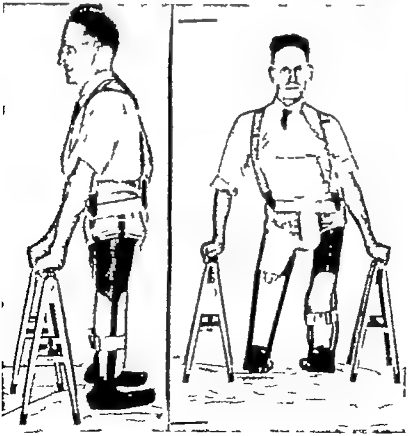

FIG. 253 Bilateral amputation of the legs. The right above-knee amputation has had a metallic hip arthroplasty The patient is walking on rocker legs as a preliminary to full length artificial limbs. Note the tetrapod form of sticks.

Fig. 254. Abscess opening in front of thigh stump. Broad incision mark—most practical area for drainage. Thin incision where scarring is undesirable.

Patient has had no children. She lives in a ground floor flat and is alone all day but this does not worry her as long as she is able to get from room to room on her artificial leg. She blames each successive operation for exacerbation of her symptoms, and refers nearly all her pains to her surgical scars. She has a miserable appearance and her sole topic of conversation is her pain and complaint against the various surgeons who have made it worse.

Treatment: Proceed with percussion.

26.1.53: Percussion therapy of no real value.

See Figs. 250–54.

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CHAPTER XIII

HEALING PROCESSES AND AFFECTIONS OF AMPUTATION STUMPS

"As is our pathology so is our practice"
OSLER.

Healing Processes

IN an amputation as in every other operation, modern surgery seeks not only to ensure healing by first intention but also to remove any focus of disease existing in the stump itself and to leave a functionally useful stump To achieve this end it is necessary to study the various reparative processes and likely pathological conditions

Amputation of the limb involves the incision of epidermis dermis, subcutaneous tissue deep fascia, muscle possibly some tendons bone blood vessels and nerves and the consequent inflammatory reaction. The mechanism of repair of these different tissues varies Let us examine these familiar processes

Inflammation

The inflammatory reaction to injury following even the incision made by the surgeon's knife is a warning of and a protection against further injury In the early stages there is hyperæmia and consequent flooding of the area with blood and lymph exudation. Large numbers of white corpuscles pass into the exudate to destroy and remove bacteria and dead and injured cells In the last stage the lymph provides the materials for the surrounding uninjured tissue cells to grow and proliferate so that the reparative process may be initiated and completed Repair if there are no complications may be complete in the case of epithelium and connective tissues in a matter of days but in the case of bone and nerves may require weeks or even months

1 **Healing of the Skin.** An incision dividing the epidermis and dermis with its connective and adipose tissues blood vessels and nerves is followed by an inflammatory reaction necessary for the reparative process

If the surfaces of the cut are brought together and held firmly in apposition they become glued together as it were by the fibrin of the clotted blood and lymph Phagocytosis clears away the hæmoglobin of the clot and injured and dead cells Fibroblasts invade the fibrin network and lay down connective tissue threads which are gradually converted into collagen fibres Blood and lymphatic capillaries formed from the endothelium of existing capillaries grow into the network of cells and fibres When the gap is thus closed by the newly formed fibres epithelial cells flow over and cover the scar tissue which, in this case is extremely thin Subsequent proliferation of the epithelial cells completes the epidermis The scar tissue or cicatrix, is firm and almost unnoticeable This is healing by first intention or primary healing

If the skin has been extensively injured, or the wound has been infected, the inflammatory reaction is much more intense but still follows the same course—hyperæmia, exudation and destruction and removal of bacteria and dead cells of the injured tissues

by phagocytes Beneath the scab of clotted blood or pus an extremely fragile glistening bright red tissue forms which because of its appearance is known as granulation tissue

Granulation tissue consists of fine threads of connective tissue laid down by fibroblasts and a network of large blood and lymphatic capillaries It provides a constant stream of leucocytes and exudate for the destruction of bacteria dilution of toxins and removal of necrosed tissue It gradually fills the gap by growing upwards from the floor and sides of the wound Epithelium spreads across and the fine mesh of fibres is gradually replaced by bundles or strands of thicker coarser fibres which as they shrink and consolidate squeeze out the blood vessels and form a scar or cicatrix of considerable thickness and denseness Poor suturing sometimes causes puckering of the uniting surfaces and the fibres become coarser and contract forming a dense unsightly and adherent scar This is healing by second intention or secondary union

2 **Healing of Fasciæ, Ligaments and Tendons** Torn or surgically divided fasciæ and ligaments heal by formation of new fibrous tissue between the ends Clotted blood or exudate from surrounding vascular tissues is organized by the invasion of fibroblasts and is replaced by fibres similar to those of the original tissue

Tendon consists of white fibres arranged in parallel bundles held together by areolar tissue The cells of which there are comparatively few are arranged in rows between the bundles It is a matter for speculation as to how tendons are re attached to muscles Some tendons are surrounded by a sheath When the ends of the sheath and tendon are sutured exudate from the vascular sheath clots and becomes replaced by granulation tissue collagen fibres form in parallel lines and finally in continuity with the fibres of the severed ends Healing is practically complete in three or four weeks

3 **Healing of Cartilage.** Cartilage seems to be repaired by formation of fibrous tissue in the usual way and only rarely by proliferation of uninjured cartilage cells New cartilage is of the fibrous type but is said gradually to change into the hyaline type

4 **Healing of Muscle** There is some considerable doubt as to whether muscle fibres regenerate If conditions are favourable and damage is not serious growth of the multinucleated sarcoplasm may take place as well as formation of new supporting tissue from the endo and perimysium Usually however scar tissue forms and establishes continuity of the muscle tissues Occasionally muscle bundles become inserted into a cicatrix and render it unstable and painful A good blood supply to the muscle fibres is necessary to prevent atrophy

5 **Healing of Nerves.** Obviously only the proximal end of the cut nerve is involved and we have to consider —

(1) The connective tissue fibres of the peri and endoneurium
(2) The neurilemma (sheath of Schwann)
(3) The axon with its myelin (fatty sheath)

Degeneration commences in the myelin sheath which breaks up into fatty globules At the same time the axon also breaks up and disappears The neurilemma and supporting connective tissues remain except for damaged cells The necrosis extends only a short distance and is removed by phagocytes

From the end of each axon fifteen to twenty fibrils grow out each ending in a bulb like swelling If the distal portion of the nerve had existed one of these fibrils would have become enveloped in a myelin sheath and neurilemma and continued to grow down

one of the channels in the supporting connective tissue united by scar tissue with that of the distal end of the nerve The other fibrils would have disappeared.

Since after amputation the distal end of the nerve no longer exists the fibrils, with regenerated connective tissue reach the underside of the flaps where they form a neuroma which is very tender to touch

6 **Healing of Blood-vessels and Lymphatics.** Following an amputation a blood clot forms and seals the large blood vessels which have been ligatured, as well as the smaller blood vessels The usual physiological processes of occlusion of blood vessels by thrombosis the organization of intravascular thrombi and the establishment of a collateral circulation take place in the stump New blood vessels develop some differentiate into arteries others into veins

Some of the old blood vessels are greatly reduced in calibre and end in fibrous cords which extend to the level of the lowest parent branch. New capillaries and lymphatics also grow from the surrounding capillaries and lymphatics In course of time the stump develops a new route of blood supply and lymphatic and venous drainage It should however be mentioned here that when the vascularity of the stump is not adequate due to disease of blood vessels or to faulty operative technique excessive atrophy of the muscle takes place and sometimes ischæmic ulcers and gangrene of the skin and subcutaneous tissues supervene

7 **Healing of Bone** After amputation the cut end of bone soon becomes covered by a mass of coagulated blood and tissue fluid In about two weeks organization takes place This organized mass resembles granulation tissue in which are multiplying osteoblasts and fibroblasts Later collagen is laid down among these fibrinous trabeculæ and a hyaline ground substance develops Calcium is deposited on these trabeculæ This network is extremely vascular and forms the callus

At this stage the bone looks like a " woven fabric " which is deposited at the end of the stump Now an attempt is made to consolidate and shape the bone Osteoblasts lay down the lamellæ of new bone while osteoclasts remove and absorb the excess callus. The " woven " bone now turns into lamellar bone The ultimate structure and shape of this new bone depends on the mechanical stress and strain e g weight bearing or the relation of the end of the bone to the insertion of active muscles

The bones in an amputation stump are nearly always less calcified than in a normal limb while the distal portions of the amputation stump are less calcified than the proximal portions The reason for this is that the more active muscle insertions are nearly all proximal and therefore the longitudinal stress which is applied at the proximal end of the stump by the muscles is greater than that at the distal end. According to Wolff's law variations in the demand on the stump are met by alterations in structure This leads to an alteration in the internal trabecular arrangement in the stump and also in the bones which are more proximal e g the hip and pelvic bones For instance the trabeculæ in the head of the tibia in a below knee amputation run downwards and outwards from the articular surface towards the condyles and the tubercle of the tibia and in the case of the fibula the trabeculæ become more distinct and also run obliquely downwards and outwards since weight is transmitted through the upper end of the tibia and the head and neck of the fibula. Below the lower level of trabeculation the shaft becomes relatively free of trabeculation the cortex becomes thinned, while the distal end of the medulla becomes enlarged and more translucent to X rays The end of the bone becomes rounded off and

sealed by a firm layer of compact bone In the radiogram immediately above this compact layer (which acts as a lid) an area of translucency with diminished or absent trabeculation can often be seen This appearance may be mistaken by the inexperienced for an area of infection

It is of importance in amputations in children to consider whether a stump is end bearing or proximal bearing End bearing stumps enable the bony pelvis to develop

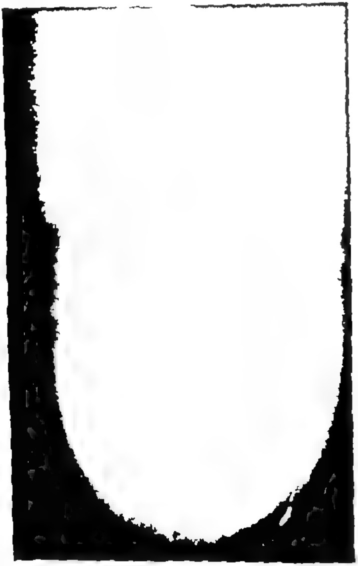

Fig 255 Old fracture of bony spur lower end of femur

along more normal lines and do not produce the same degree of pelvic under-development and asymmetry that proximal bearing stumps do This is particularly important in girls

Spurs and Osteophytes Most distal ends of amputation stumps particularly of the lower extremity become the sites for bony outgrowths known as osteophytes spurs or exostoses These spurs are normal constituents of amputation stumps and can be divided into ten morphological groups Their origin is always the same—from the periosteum although their ultimate form depends upon local tissue conditions and the

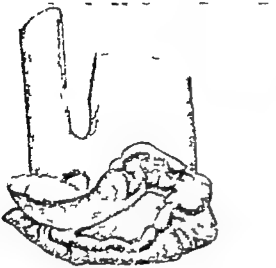

Fig 256. Amputated stump segment showing cross-union and an ulcer adherent to the lower end of the tibial stump.

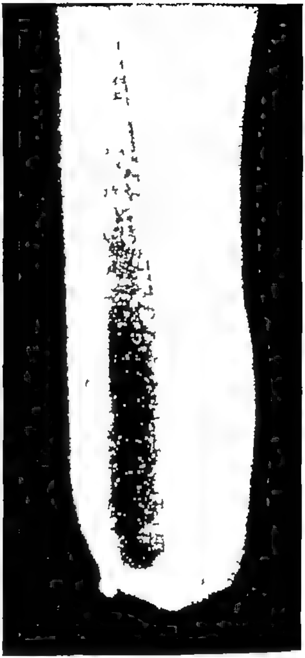

Fig 257 Below knee amputation. Here again the stump is too long and cross-union has occurred between the lower ends of the tibia and fibula.

remodelling of the stump They are usually composed of cancellous bone with a covering of compact bone

(1) The first and commonest groups point upwards and usually medially They are essentially due to traction and are best seen in the above-knee stump where the adductors provide the pull (Fig 255)

(2) The second group are mushroom-shaped spurs consisting of compact bone situated more or less regularly over the distal cap and covered by a layer of ivory like bone of very considerable density and hardness End bearing usually produces this.

(3) In this group are spurs which point downwards they are sharp lateral or medial but never central These are due to a displaced cuff of periosteum which has increased in size due to pressure They are usually painful and may be surrounded by an adventitious bursa which sometimes aggravates the pain

(4) In this group cross union occurs in amputation stumps below the knee and below the elbow It is more common in the former In itself it is not necessarily a serious complication but *it may be accompanied by adherent skin* which becomes the site of an indolent ulcer (Fig 256) Some writers welcome cross union but I have not been able to agree with them because the tendency to cross union in a below knee stump

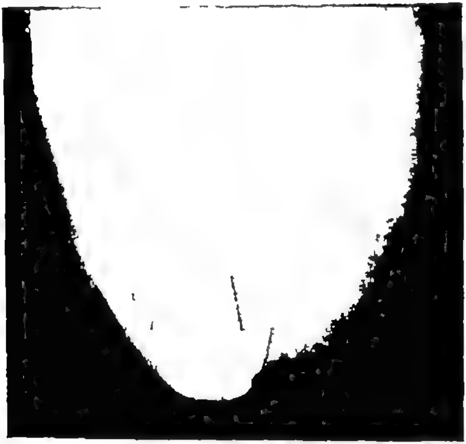

Fig 258 Bony spurs on lower end of femur

eliminates the natural resiliency which is so necessary for comfortable limb wearing without pressure complications (Fig 257)

(5) The fifth group are umbrella shaped A cuff of periosteum may become displaced and surround the distal end of a bone giving the end of the stump a hollowed-out appearance somewhat *like the interior of an umbrella (Fig 258)*

(6) The sixth group—stag horn spurs—usually occur high up in single bone amputations particularly on the medial side near the lesser trochanter These are large irregular spurs and do not give trouble

(7) The seventh group—elongated spurs on the *medial side of above knee stumps*—are ossifications in the adductor muscles They usually follow infections they are seldom painful and it is a mistake to endeavour to remove them Rarely they may be fractured.

(8) The eighth group—horizontal spurs—run irregularly at right angles to the distal end of the bone and are due to displaced periosteal tags. They do not give rise to pain as a rule and do not call for surgical interference (Fig. 259)

(9) The ninth group—raspberry-shaped spurs—are large masses of irregular calcification situated on the end of a bone with large convolutions and deep sulci. The sulci are

Fig. 259. Complex bony spur directed medially from lower end of stump of the femur

filled with fibrous tissue. An adventitious bursa usually forms over the end of the spur and may cause considerable pain

(10) The tenth group. The conical stump of childhood is a terminal spike of growing bone which is so pointed that it penetrates the skin if allowed to grow. Such spurs also occur in adults; though they do not penetrate the skin they cause a painful bursitis at the end of the stump (Fig. 260)

At this stage it is necessary to mention the periosteal proliferation which takes place in a stump. This membrane is highly sensitive and is easily stimulated by friction or pressure causing permanent proliferative changes to develop rapidly and become a source of obstinate pain to the patient

Hirsch first recognized and called attention to the fact that stumps stripped of their periosteum are quite useful In his method as in most ancient methods Hirsch does not preserve the periosteum At a surgical congress in Berlin in 1901 this method was generally accepted Bunge from von Eiselsberg s Clinic declared that it was injurious to cover the stump with sensitive periosteum and that on the contrary it should be removed as the stump would become more useful because it was less sensitive

The only exception to this rule is in the case of below knee amputations where the

Fig 260 Pointed conical stump with cross-union of tibia and fibula. Note how the bone is pushing the skin out

deep fascia is continuous with the periosteum in front Here the periosteum is incorporated in the fascial flap which is sutured as a separate layer over the end of the whole stump

A Healthy and Useful Stump

If the processes of healing which have been described take place without any infection or pathological lesion we can expect a useful and healthy stump The ideal stump is a smooth tapering part of the limb segment which terminates in a truncated cone This articulates with the trunk or with a proximal bone at a joint The joint has a full range

of movement and the muscles are well developed and re adjusted. The skin is healthy possesses a good blood supply and is free from adherent scars There are no skin sulci and no redundant flaps The skin is free from infection and there is no enlargement of the regional lymphatic glands The subcutaneous tissue is supple and mobile There is no œdema or *peau d orange* The stump is not flabby because of atrophic muscle or excessive subcutaneous fat or both A flabby stump allows marked rotation of the soft tissues even when the muscles are tensed. The muscles in an ideal stump serve as a pad and perform the function of activation These muscles give the stump its tapering contour and enable good fitting of the artificial limb to be accomplished.

The ideal length of the stumps has been discussed in a previous chapter

Without any pathological complication and by correct surgical procedure it is possible to obtain a so-called perfect stump in a great majority of patients This enables the limb fitter to achieve the highest degree of success in his craft

Affections of the Stump

Skin Lesions The skin lesions however minute they appear are nevertheless of great importance because they prevent a patient from using his artificial limb

Furunculosis Furunculosis of the skin of the stump as elsewhere in the body is caused by staphylococcal infection of the hair follicles and sebaceous glands These boils cause great inconvenience to the amputee They occur in the groins and over pressure areas and are usually associated with faulty stump hygiene

TREATMENT Cleanliness of the stump is the first effective prophylactic measure—application of rectified spirit over the stump mild antiseptic soaps and, in more severe cases appropriate antibiotics Refrain from limb wearing until the boil is healed

Folliculitis This is a common condition found in the stumps and is often aggravated by the use of the artificial limb It is also staphylococcal in origin Treatment is essentially the same as for furunculosis

Heat Rash. Those rashes over the skin are more common in the tropics and in warmer climates than in temperate and cold zones

Treatment consists of refraining from use of the artificial limb and applications of rectified spirit followed by a good brand of talcum powder to the stump

Dermatitis. Dermatitis of the stump may be a local condition or a part of the general involvement of the body It may be due to the use of strong soaps or powerful antiseptics The stump may also develop skin lesions due to drug sensitivity e g antibiotics or allergy

Treatment includes that of the general condition and abstaining from the use of the artificial limb

Intertrigo This occurs in puckered and indrawn scars caused by limb wearing The two folds of skin rub each other and an area of redness appears The protective layer of keratin on the surface is removed by friction. Infiltration with inflammatory cells is followed by fibroblastic proliferation Infection with pyogenic organisms occurs In summer this is particularly irritating and very painful to the patient

TREATMENT—*Prophylactic* Thorough stump hygiene The treatment is surgical Excision of the scar wherever possible and suture so as to obtain a linear scar

Eczema. The skin of the stump is a not infrequent site of eczematous involvement two types of which may be seen —

(1) *Ulcer Eczema* Here we find the eczematous condition of the skin surrounding a discharging sinus This condition which is the result of chronic irritation by the discharge and may be due to a low grade bacterial infection clears up when the sinus heals

(2) *Eczema of the Whole Stump* There is often a spreading involvement of the distal end of a stump The ætiology of this condition is obscure It may be due to a vascular disorder the skin gradually becomes congested and swollen the cells undergo chronic inflammation and fibrosis may occur There is often a watery discharge when this condition resembles weeping eczema elsewhere in the body

Fig 261 Sinus at the end of an above-knee stump. Generalized eczema of the skin

TREATMENT *Generalized Eczema* Refrain from limb wearing and treat with ultra violet light and zinc oxide ointment

Sinus Eczema of Stump Treat the sinus and eczema generally clears up after the sinus has healed (Fig 261)

Sebaceous Cysts

These cysts which are not common occur in amputation stumps in the lower extremity particularly in above-knee amputations The more common sites are in the adductor region and in the groin and occasionally on the inner aspect just below the knee in below knee amputations This condition occurs more frequently in persons who are casual in matters of personal hygiene

The cause is due to the constriction of the mouths of the sebaceous glands in these sites Whereas normally these glands secrete and their ducts remain open in the case of an amputation patient wearing a woollen sock tightly pressed upon by the socket of the artificial limb the ducts soon become occluded if daily washing both of the stump and sock, is not routine Some patients powder themselves without washing This powder merely cakes at the mouth of the duct and further blocks it The glands become distended and infected with staphylococci and due to the piston action of the stump in the artificial limb in that area they rupture This troublesome condition is most incapacitating and difficult to eradicate The cure is first in prophylactic cleanliness both of the stump and the sock, and second a well fitting socket of the artificial limb

If conservative treatment will not cure resort has to be made to surgery the cysts infected fat and the deep fascia should be excised down to the muscle If there are small sinuses these too should be excised together with any skin which is thickened inflamed and irregular

In such cases it is wise to wait until infection has settled down this may take some

weeks Prophylactic penicillin is of value In excising this area hæmostasis must be meticulous and drainage should always be instituted. It is of the first importance that the scar should be vertical because horizontal scars not only give a larger area for the socket to rub against but cut through a great number of veins and lymphatics in that area. This leads to a chronically swollen stump difficult to fit and the patient is unable to wear his artificial leg for more than an hour or so a day

Post-traumatic Cysts

These post traumatic epidermoid cysts appear in the skin in the adductor region of the thigh along the line which corresponds to the upper rim of the socket in an above-

FIG 262. Amputation stump showing pigmented skin and sinuses and nodules along upper antero-medial line of apposition of prosthesis.
[F Young The Lancet

FIG 263. Chronic granulation tissue showing large giant-cell enclosing cornified epithelial cell.
[F Young The Lancet.

knee prosthesis They occasionally occur also on the inner aspect below the knee in below knee amputations

At first the cysts disappear or become quiescent with rest from wearing the limb but in time they become larger and multiply and the skin may break down become secondarily infected and discharge pus with resultant chronic sinuses which may track into the scrotum or vulva The skin in the infected region frequently becomes lumpy indurated and pigmented (Fig 262) At this stage it is impossible for the patient to wear a prosthesis and he has either to take to his crutches or remain in bed

Careful sections by Frieda Young through excised specimens all reveal small rounded areas some with and some without central softening There are also some rounded areas which are outlined in the formalin fixed tissue by a thin white line

Microscopic examination shows areas of non specific inflammatory tissue composed of lymphocytes plasma cells and in cases undergoing softening polymorphs These are surrounded by a zone of young capillaries and fibroblasts or fibrous tissue Foreign body giant cells can always be found and may be numerous and even collected into follicles (Fig 257) Some follicles show central cavities which may contain amorphous eosinophilic material Small cystic spaces are usually seen These are lined entirely by stratified squamous epithelium in which there are usually no dermal papillæ and are filled with concentric layers of keratin (Fig 263) Some of these cysts are surrounded by or in close contact with cells forming a non specific chronic inflammatory reaction No hairs or sweat glands have been identified in the walls of any of the cysts Many of them

Fig 264 Cyst lined by squamous epithelium and containing concentric layers of keratin.
(F Young The Lancet.

Fig 263 Fragment of skin epithelium lying free in the midst of chronic inflammatory cells.
(F Young The Lancet

are microscopic in size but some are large enough to be visible to the naked eye and their lining of skin is then seen as a thin white line

The pus which is obtained from a discharging sinus contains not only polymorphs but squamous epithelial cells No single causal organism of infection has been identified It appears therefore that the condition is one in which the surface epithelium is displaced into the corium either in the form of single cells or cell nests or else there is invagination of the skin in its entire thickness (Fig 264) The result is the production of non-specific inflammatory tissue and of implantation epidermoid cysts

The underlying cause of this condition is the piston action which is imposed on the stump by the badly fitting socket of an artificial leg Each time the weight is put on to the limb the stump is pushed into the socket and pressure occurs at the upper rim of the limb Intermittent pressure also occurs in well fitting limbs but *friction* should not do so In these cases the pressure is unevenly distributed being mainly on the anterior and medial edge When the weight is taken off the leg the pressure is released It is conceivable therefore that this oft repeated pressure and release will cause some displacement of the skin Presumably epithelium is forced inwards into the corium Bland-Sutton in 1891

weeks Prophylactic penicillin is of value In excising this area hæmostasis must be meticulous and drainage should always be instituted It is of the first importance that the scar should be vertical because horizontal scars not only give a larger area for the socket to rub against but cut through a great number of veins and lymphatics in that area This leads to a chronically swollen stump difficult to fit and the patient is unable to wear his artificial leg for more than an hour or so a day

Post-traumatic Cysts

These post-traumatic epidermoid cysts appear in the skin in the adductor region of the thigh along the line which corresponds to the upper rim of the socket in an above-

FIG 262 Amputation stump showing pigmented skin and sinuses and nodules along upper antero-medial line of apposition of prosthesis. [F Young The Lancet

FIG 263 Chronic granulation tissue showing large giant-cell enclosing cornified epithelial cell [F Young The Lancet.

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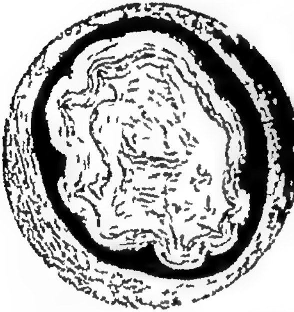

Fig 264 Cyst lined by squamous epithelium and containing concentric layers of keratin
(F Young The Lancet)

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and King in 1933 described cysts resulting from recurrent traumata This injury need not be perforating Here we have a state in which the trauma is oft repeated. It appears therefore that this condition previously described inaccurately as that of sebaceous adenoma, is really a form of post traumatic epidermoid cysts

A typical case is that of Mrs S At fifteen years she had an amputation of the right leg above the knee following osteomyelitis She had an artificial limb soon afterwards Eleven years later one small lump developed in the adductor region which remained uninfected for one year It ultimately became infected and developed a discharging sinus Since then numerous lumps have developed and the whole area is so painful that she is unable to wear a prosthesis (Fig 265) There is a thickening of the skin in the adductor region of the right leg in which small shotty nodules can be palpated. Between the nodules the tissue appears to be normal There is a well healed oblique scar the site of previous operative removal in this area. Sections show the typical histological picture already described.

These cysts are intractable and recurrent and cause much disablement among artificial limb wearers

TREATMENT (1) Abstain from limb wearing (2) Adjust the socket and alter it to a more suitable type (3) Paint with iodine (3 per cent) (4) Local injections of penicillin (5) Express the infection and, if necessary perform local curettage (6) Operate as described under sebaceous cysts This is not advised except as a last resort for it does not yield good results

Cellulitis

A condition resembling erysipelas is occasionally seen in the stumps The onset is sudden. The skin of the stumps becomes red and painful and a skin edge develops Usually the distal end of the stump length is involved Suppuration never occurs The onset of the clinical symptoms is acute There is a rise of temperature (103 F) prostration, nausea and vomiting

The ætiology of this condition is unknown It is believed to be a streptococcal infection of the lymphatics of the skin

Treatment (1) Refrain from using a prosthesis (2) Rest the stump (3) Apply local hot and cold dressings (4) Penicillin and sulphonamide therapy

Diphtheritic Infection of the Stump

Several cases have been seen of typical infection of the stump by a virulent strain of Klebs Loeffler bacilli with the formation of a false membrane over the skin accompanied by toxic symptoms

Treatment. The treatment and general care of the diphtheritic stump is the same as in any severe diphtheritic infection of the throat or elsewhere

Ulcers of the Stump

Stumps are frequently sites of ulceration. Both acute and chronic ulcers are found at the end of the stump

1 **Acute Ulcers.** These ulcers occur on a healthy stump and are caused, as elsewhere in the body by a persistent irritation such as the trauma resulting from the artificial limb Destruction of epithelium takes place and a clean wound occurs which soon becomes

infected by pathogenic organisms In the acute stage granulation tissue is formed and there is a thin discharge Healing takes place in the usual way by the breach filling up with granulation tissue In course of time epithelium grows over the raw surface and brings about the continuity of the surface

TREATMENT (1) The amputee should abstain from using his artificial limb (2) Fomentations and antibiotics are used in the same way as in the treatment of an acute ulcer

2 **Chronic Ulcers** Most chronic ulcers occur at the end of the stump and are a great source of trouble to the amputee and the surgeon They are found mostly in below knee stumps

The following are the types of chronic ulcers seen —

(a) DOUGLAS ULCERS Douglas made a study of the pathology of non healing trau

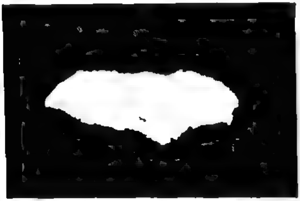

FIG [illegible]06 Unstained cross-section of the non healing portion of the scar Under the floor of the ulcer is hyaline fibrous tissue This also forms a wedge between muscle bundles.

FIG [illegible] ([illegible]60) Weigert's iron hæmatoxylin and Van Gieson The muscle sheath having been broken frayed out muscle fibres (on the left) are seen extending into the very firm scar tissue

matic ulcers which followed surgical operations The ends of stumps are the usual sites for such callous or indolent ulcers

These ulcers remain unhealed in spite of all methods of conservative treatment

Normally the mobile subcutaneous tissue containing blood vessels nerves and sweat glands allows the dermis or true skin with its epidermis to be moved freely over the deep fascia muscle or bone lying beneath it

In the case of an amputation the cut end of the muscle is now no longer surrounded with its sheath of connective tissue If there is not sufficient fascia to cover the cut end the muscle becomes attached to the scar tissue which is firm and hard The muscle fibres can be seen embedded in the firm connective tissue years after the original amputation and if an ulcer develops it can be seen to be drawn up by the muscular movement If the skin breaks over the end of a bone and exposes the periosteum healing takes place from the floor of the wound, and the firm scar tissue fixes the ulcer to the bone The

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normal blood supply to the ulcer area was interfered with A series (70) of microscopic investigations has revealed this entrapped muscle in the scar tissue (Figs 267-69)

Treatment To eradicate this ulcer satisfactorily and make the stump fit for limb-wearing the surgeon should bear in mind the pathological condition It is necessary to sacrifice more bone Merely to excise the ulcer is to invite further pathological complication Bone and fibrous tissue must be liberally excised, and then the fascia and skin approximated as in a primary amputation Success in these stump revisions always

Fig 270. This patient has worn a limb and has developed a chronic ulcer which will not heal by conservative means and stand up to limb-wearing Excision of ulcer with fibrous tissue and muscle and resuture.

depends on the presence of sufficient skin and the exclusion of muscle fibre from the resultant scar (Figs 270-71)

(*b*) Chronic Pyogenic Ulcers Infection of an amputation stump with pyogenic organisms is a frequent complication Chronic pyogenic infection with ulceration may occur when the stump edges have not been satisfactorily approximated by sutures which have been placed under tension and by inversion of the skin If treatment of acute traumatic ulcers is neglected and limb wearing is continued these ulcers become chronic In this type of ulcer with its pale and scanty granulations the floor becomes indurated and the skin area around pigmented These ulcers are usually *superficial* and unlike those described by Douglas are not adherent to bone or muscle

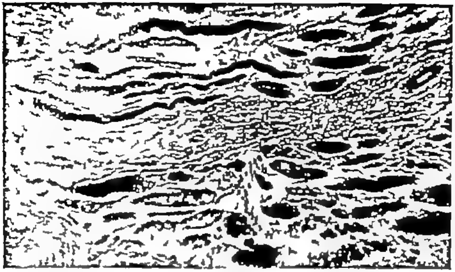


FIG 268 (× 200) Weigert's iron hæmotoxylin and Van Gieson. Muscle fibres extending into the hard scar tissue. These fibres must have splayed out into the soft lymph at the time of the first amputation.

subcutaneous tissue is obliterated by fibrous tissue, this interferes with the blood supply producing a condition which is unfavourable to the healing of the ulcer

An illustration of what occurs can be seen in Fig 266 This is a callous ulcer in the scar of the stump of an amputated leg Beneath the ulcer there is a very hard fibrous tissue The subcutaneous layer has been completely obliterated and the frayed muscle fibres pass from the underlying muscle into the scar tissue some distance from the main muscle (Fig 260) This association of chronic ulcer formation with included muscle and firm fibrous tissue might be explained by the fact that the subcutaneous tissue under the ulcer was replaced by the adjacent muscle and fibrous tissue and consequently the

FIG 269 (× 500) Weigert's iron hæmotoxylin and Van Gieson. Under the high power the cross-striation of the muscle fibres can be seen

have disrupted the basement membrane These columns display cell nests in their central parts while at the periphery an attempt at prickle cell formation is seen The tumours ulcerate and form malignant ulcers Different grades of malignancy are met with

TREATMENT Re amputation X ray and radium therapy

Case Report

Patient wounded in the right leg in 1918 at the age of eighteen years The tibia was extensively damaged and in thirty years the resultant sinuses never healed completely There were many sequestra and at least seven operations were performed In 1946 radiographs showed large cavities in the upper and lower end of tibia; sclerosis of surrounding bone; synostosis with the fibula opposite each cavity and periosteal new bone formation around the middle third of the fibula At that time there was much discharge Histological examination of curettings from the sinus showed squamous-cell carcinoma Amputation was performed 11 in below the greater trochanter A year later the patient was re-admitted with enlarged inguinal glands clinically inoperable His general condition was poor and radiographs of the chest showed a collapsed right lower lobe

FIG 272. Bulbous and oedematous (first stage) end of stump due to ill fitting socket

FIG 273. Extensive hyperkeratosis in a below knee stump This is due to an ill fitting socket and the line of demarcation can be seen.

Treatment consists of (1) abstaining from limb-wearing (2) control of the infection by appropriate chemotherapy or antibiotics (3) ultra violet light therapy

Ulcers following Venous Congestion of the Stump Ulceration of the skin may occur when there is venous congestion or circulatory disturbances due either to unsatisfactory limb fitting or vascular disease of the stump

Specific Chronic Ulcers These include gummata and tuberculous ulcers They are an uncommon feature in an amputation stump although I have seen a tuberculous ulcer in an above-knee amputation in a patient suffering from pulmonary tuberculosis

FIG 271 The result of excision of the ulcer with production of a vertical scar which was unavoidable in the circumstances.

Malignant Ulcers. These are found in stumps which are the seat of malignant glands —usually in above-knee amputations with glands in the groin The glands ulcerate

TREATMENT At this stage surgery or deep X ray therapy is too late because of (1) the presence of metastases and (2) superimposed secondary infection. Treatment can only be palliative

3 **Squamous Cell Carcinoma.** These malignant growths supervene in old scars and in indolent ulcers of the stump in connection with sinuses Papillomata may also become malignant The tumours show downward growth of columns of epithelial cells which

FIG 275 Same case View from the medial side

FIG 276. Large cauliflower growth at the end of a below knee stump. Papilloma. This was the result of an ill fitting socket

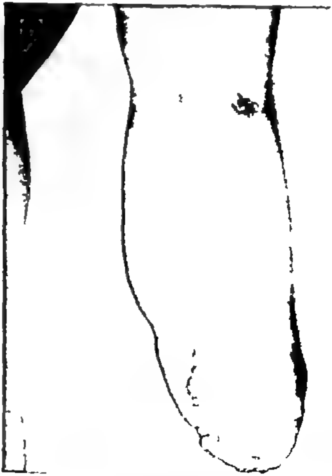


FIG 277 Same stump posterior view with papillomatous growth showing pigmented line at lower end of thigh where the socket has constricted it

with effusion. He died within three weeks of admission. At autopsy there was carcinoma in the amputation stump and in the inguinal glands, as well as in the lungs diaphragm and pleura.

Comment. This case presents certain notable features the malignant change began with a sinus and was already well established before much surface change was evident the tumour itself was highly malignant and metastasized widely the glands should have been excised at the primary amputation

Tumours of the Skin

1 **Hyperkeratosis** This is a condition in which the skin of the stump becomes thickened irregular and rough and is mainly due to an ill fitting socket which causes

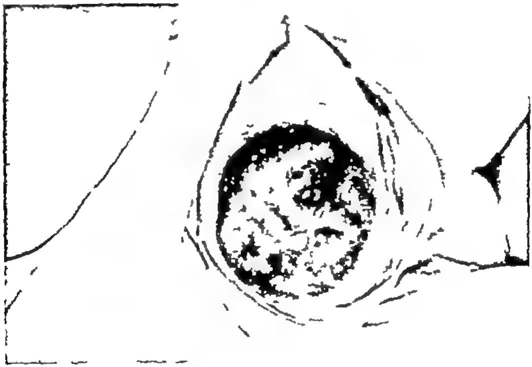


FIG 274 End of above-knee stump with a plug fit Stump is œdematous, pigmented and hyper keratosis is well advanced. Different shape of socket advised after revision of stump

undue pressure resulting firstly in œdema and then in chronic skin changes It occurs usually at the end of the stump in deep and invaginated scars where the stump is taking a certain amount of pressure It becomes painful (Figs 272–75)

TREATMENT Refrain from limb wearing soften the skin with zinc oxide and castor oil ointment and then excise the hyperkeratotic area together with the neighbouring infolded scar and improve the cosmetic state of the stump

2 **Simple Papillomata.** These may be found at the end of the stump Corns and callosities result from unequal distribution of weight over the surface of the stump or weight bearing over unsuitable sites on the skin of the stump Sometimes projecting growths assume large dimensions These large papillomatous growths occur at the end of a stump following years of limb wearing when sockets are badly fitting (Figs 276 277) They are composed of many layers of squamous epithelium The superficial layers

Fig 275 Same case View from the medial end

Fig 276 Large cauliflower growth at the end of a below knee stump. Papilloma. This was the result of an ill fitting socket

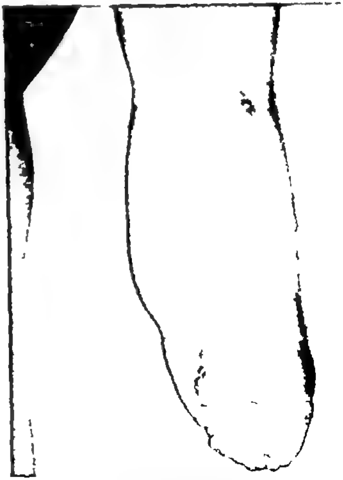


Fig 277 Same stump, posterior view with papillomatous growth showing pigmented line at lower end of thigh where the socket has constricted it

Fig 278 Papilloma at the front of below knee stump Note its relation to pigmented line produced by socket of the artificial limb.

undergo excessive keratinization. They never invade the deeper structures and are harmless so long as the germinal layer of the epidermis remains intact

TREATMENT *Surgical Excision* Re-amputation with resection of the regional lymph nodes (Fig 278)

Redundant and Adherent Folds of Skin

Redundant Folds of Skin and Subcutaneous Tissue In some instances the socket of an above-knee amputation becomes too small. As the stump is pushed into the socket and the body weight is supported by it the skin is pushed up on the inner side of the socket This site is one of the first areas where the integument comes into contact with the socket The result is that this area of skin and subcutaneous tissue does not enter the socket It is now subjected to the plunging movements of walking and hangs over the rim of the socket

At first the formation of a roll of tissue is temporary and disappears soon after the removal of the constricting socket Soon however fibrosis takes place at the base of the roll of tissue owing to repeated minor trauma, and the roll of subcutaneous tissue becomes permanent It forms an overlapping mass which can now readily be nipped between the adductor tendons and the trumpet-shaped mouth of the socket These rolls of tissue occur with sockets which are too tight owing to the fact that the stump has hypertrophied. On the other hand, they may form during the shrinking phase of the stump In such cases the loose skin and subcutaneous tissue is displaced outside the socket by the piston action To attempt to diminish the size of such a socket by lining it will only increase the effect

Frequently this condition occurs in older amputation cases particularly those which have been amputated for ten to fifteen years A roll of tissue may develop on stumps which for a number of years have been satisfactory This roll of tissue then becomes troublesome particularly above the top of the rim of the socket and usually in the adductor regions The cause of this roll is here due to a combination of factors—firstly the patient gets older and may become fatter and secondly the constant wearing of an

artificial limb produces a redundancy of skin, due to the constant piston action and little by little the skin becomes heaped up at sites which are somewhat remote from actual pressure areas but nevertheless adjacent to them Thirdly some of the muscles in the stump atrophy and the subcutaneous tissues in those sites undergo a fibro fatty change Soon this redundant skin with its underlying fibro fatty mass becomes adherent to the deeper tissues In the groin it is adherent to the adductor muscles and at the distal end of the stump it may be adherent to the end of the bone or the muscle laterally or posteriorally The surprising thing about these stumps is that whilst originally the artificial limb fitted well owing to the increased amount of tissue viz skin and fibro fatty replacement the socket no longer fits and the roll of flesh tends to push the socket off

TREATMENT Frequent inspection of the socket as to its suitability is of the utmost importance before the condition becomes established The treatment is to attempt to fit a more suitable socket If limb fitting does not improve this surgical removal becomes necessary The incision if in the length of the stump should always be vertical The excess skin should be excised together with the fibro fatty mass which is of a rubbery texture thick and adherent to the deep fascia

Before the skin is sutured it is a good policy if at all possible to close the gap caused by the removal of the mass in the deep fascia This can generally be achieved without a great deal of tension on the deep fascia The skin can then be neatly sutured over this and an attempt made to place the scar of the skin so that it does not coincide with the sutured deep fascia These operations should be performed with a tourniquet applied and after release of the tourniquet all the bleeding vessels should be carefully ligated. Drainage of the deep tissues through a small stab wound is of primary importance

Skin Adherent to Bone without Ulceration

This usually occurs in femoral stumps but may occur in other stumps The skin becomes firmly adherent to the transected femur or tibia Mushrooming of the tibial stump provides a larger base for end bearing The circulation is adequate except in longer stumps and ulceration does not occur There is however sustained nerve-ending irritation which results in pain and makes re amputation necessary

In planning a re amputation in these cases the surgeon should be guided by the length of the bone but—even more important—the condition of the neighbouring skin The object must then be to fashion the skin flaps in such a way that they will not be subjected to undue pressure The flaps should not be situated at the end of the bone where the tendency for the scar is to become adherent to the bone again and where the risk that piston action may force the bone through the skin is always maximal

Stumps with these complications are often very thin and pencil like at the terminal end and the surgeon must be prepared to sacrifice 2½ or 3 in (6 or 7 5 cm) of bone in order that the sutured skin will not be under tension During the operation he can best assess this by trial and error The atrophied end of the muscles which are already very much attenuated should be retained as they have a double value Firstly they offer nutrition to the adjacent skin and secondly they can be utilized by a few well placed sutures to separate the skin from the cut surface of the bone

Adherent Skin with Ulceration

Ulcers adherent to stump ends particularly bones invariably require re-amputations. The ulcer adherent to the bone takes a long time to heal by conservative means and when it is healed it is soon likely to break down again with limb wearing and the associated piston action End bearing stumps with thin papery skin attached tend to atrophy from

Fig 279 Large chronic ulcer at the end of a below knee stump which has followed limb-wearing A guillotine amputation was originally performed. Re-amputation.

pressure and from ischaemia (Fig 279) With time and adaptation, the underlying bone bed becomes entirely compact and the adherent skin may develop intractable ulceration. Re-amputation at a suitable site and re fashioning the stump according to the best surgical routine is the only satisfactory alternative

Redundant Lateral Folds of Skin

It often happens while performing primary amputations and trimming stumps that

redundant lateral folds of skin result at the suture line This is not always due to bad fashioning of the flaps but is often necessary because of the scarring and irregularity of the stump The best method of dealing with this unsightly complication is to suture the wound almost to the point where the fold becomes excessive at the lateral end of the wound after which a V shaped area of excess skin is excised The deeper tissues are cut more obliquely than the superficial It will then be found that although the length of the incision is larger it is nevertheless linear and there are no excess lateral folds at the periphery

Lesions of Muscle

Contracture of Muscle After amputation there is a tendency for the knee to flex the hips to abduct and flex and the shoulders to adduct The contraction of muscle at first is due to protective spasm as a result of irritation or infection in the stump The remaining muscles have a tendency to pull which if left connected may become permanent

1 **Flexion Contractures in Short Below-knee Amputations** A below knee amputation is a much more desirable type of amputation than an above knee and every effort should be made to save the knee joint In the early stages it may be possible to reduce the flexion contracture by manipulation followed by wedge plasters Soon however fixed flexion contractures of the knee joint result in the tibia being displaced backwards laterally and externally rotated on the femur—a triple deformity It now becomes a difficult surgical procedure to correct this deformity and preserve the integrity of the knee joint as a functional entity

2 **Flexion and/or Abduction or Adduction Deformities of the Hip** Some flexion deformity always occurs but marked flexion deformities of the hip in above knee amputations are disabling particularly in double amputation cases It requires a great deal of difficult adjustment on the part of the limb maker to compensate for these deformities He can fit a socket to the stump and then compensate for the deformity by allowing the normal axis of the limb to meet the socket in such a way that the junction between the two though angled and corrective is yet not apparent When the deformity of the hip is gross the apparatus then becomes cumbersome and unwieldy and the surgeon may have to step in and perform an osteotomy

3 **Muscular Atrophy** Wasting of an amputation stump occurs because of disuse This atrophy is progressive but at a certain stage it becomes stationary It is only then that a permanent prosthesis can be fitted to the stump The stump is then said to be consolidated '

Lesions of Nerves

We have already referred to the bulbous masses which are present at the cut end of nerve trunks These so-called amputation neuromata may become adherent to the bone or muscle or scars causing pain when the prosthesis is used The various conditions which cause stumps to become painful have been dealt with in Chapter XV If the pain is due to a neuroma it usually improves with treatment (Fig 280)

TREATMENT Short wave diathermy or ultra-sonic therapy Local infiltration with novocaine 2 per cent 5 c c and Durocaine 5 to 10 c c have all been used with some success If this treatment does not relieve pain the excision of the neuroma is suggested. When the neuroma is adherent to the scar and muscle tissue a trimming operation of the

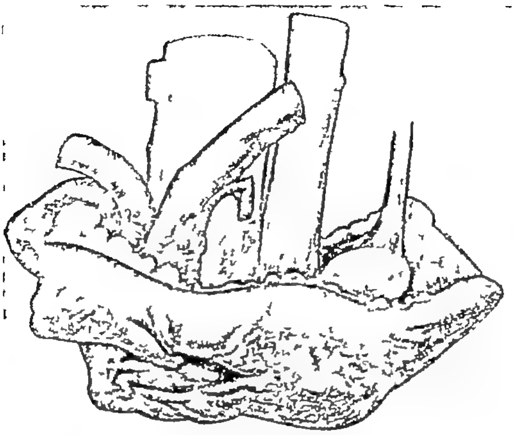


Fig 280 Amputated stump segment showing neuromata attached to base of ulcer

stump should be performed. Failing this operation neurectomy at the appropriate level is a useful procedure which may relieve the symptoms

Lesions of Blood-vessels

1 **Hæmatoma.** Hæmatoma formation in a stump that would otherwise heal by primary intention is a tragedy The blood oozes from the cut surface of the muscles and collects in the subfascial spaces if the blood vessels and bleeding points are not properly secured and ligatured. Secondary infection is almost inevitable Quite often the limb has to be amputated because of gangrene or chronic osteomyelitis following a compound fracture Where there has been a great deal of skin infection œdema occurs The tissues around the amputation area are heavily infected with organisms because the lymphatics and veins of the diseased area must of necessity drain through the operative site proximally A hæmatoma in such a site becomes an admirable culture medium. The avoidance of a hæmatoma is, therefore a primary consideration. Strict attention should be paid to hæmostasis and aseptic technique In all these cases one should administer wherever possible penicillin or one of the sulphonamide drugs prophylactically and during the stage of healing Should a hæmatoma occur this can be aspirated under aseptic conditions and the best site is usually opposite the suture line in the line of the hæmatoma A wide-bore needle is the best for aspiration. Repeated aspirations may be necessary The stump very often oozes blood and serum for weeks afterwards

and finally an incision may have to be made to evacuate the clot The surgeon should pocket his pride take the patient to the operating theatre and preserve the stump

2 **Calcified Hæmatoma** This is a rare complication and occurs on the side of the stump It may follow an injury and becomes aggravated by continuing limb wearing or by resuming it too soon The hæmatoma forms and organization takes place at the periphery with deposition of calcium The centre of the hæmatoma undergoes liquefaction the patient complains of some discomfort and is unable to wear the limb Radiograms show a calcified swelling is present (Fig 281) At operation the calcified swelling contains some brownish fluid

Case Report

Patient Mr W This patient who had been wearing a below knee artificial limb for twenty two years presented himself with a swelling on the front and lateral side of the middle of a below knee stump which was 8 in in length.

The stump was well healed and healthy and the patient s complaint was that recently it had started to pain him and had made limb wearing difficult He had been forced to leave off his artificial leg

The swelling was superficial not attached to the skin and not movable At operation this was dissected out and was found to be about the size of a goose s egg with a hard fibrosed and calcified capsule containing thick altered blood The wound healed without difficulty and the patient was able to resume limb-wearing

3 **Chronic Venous Congestion of Stump (Choked Stump)** Stumps may be the site of chronic venous congestion This condition follows excessive scarring of the stump excessively long stumps (especially in the lower third of the leg or forearm) and cases which have been amputated because of peripheral vascular disease Sometimes an inaccurately fitting socket causes œdema this can however be overcome by removing the constriction in the socket or correcting the defect in the prosthesis e g (1) tight socket (2) suction limb The stump is cold and cyanotic The skin at times is blanched and breaks down forming an ulcer This complication is frequently accompanied by intractable pain and may require re amputation

TREATMENT (1) Refraining from using a prosthesis
(2) Adjustment to the socket for size and alignment
(3) Rest and elevation of the limb
(4) Supporting bandage
(5) Local treatment of ulcer
(6) If these measures fail re amputation at a higher level

4 **Gangrene due to Vascular Lesions.** The types of gangrene which necessitate amputation have been detailed in Chapter VI It should be mentioned that the stump may also be the site of gangrene or sloughing

The main peripheral vascular lesions that cause gangrene are arteriosclerosis diabetes thrombo angitis obliterans embolism and vascular thrombosis All these generalized conditions may cause gangrene in the stump for it should never be forgotten that although the limb has been amputated the vascular disease which necessitated it still remains

TREATMENT Re-amputation at a higher level after clinical examination and assessment of the circulatory sufficiency by the various tests

Local thrombo-embolic gangrene requires special consideration This is a form of subcutaneous gangrene which is associated with *thrombo-angitis obliterans* or endarte-

FIG 281 Below-knee amputation. There is extensive periosteal new bone formation on the outer side of the fibular shaft following injury to lower end of stump (Calcified hæmatoma at operation.)

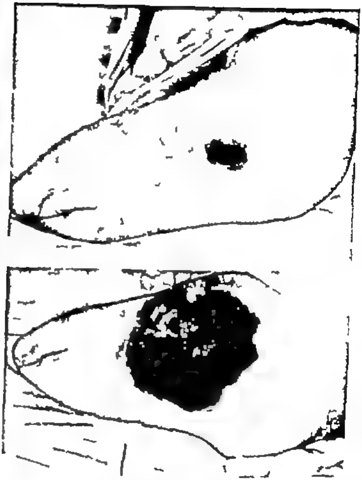


FIG 282 Thrombo-embolic gangrene in a case of Buerger's disease. Rapidly spreading gangrene in interval of a few days. The patient died shortly afterwards with a generalized septicæmia. The condition spread rapidly to the thigh and sacrum.

ritis obliterans It may occur as a post-operative complication or appear in a stump which has been amputated and healed. It is fulminating begins as a spreading gangrene which starts at the end of the stump over pressure areas e g in the region of the trochanter and spreads subcutaneously round the gluteal region to the lumbar area (Fig 282) The patient becomes toxic and runs a swinging temperature but no particular organism can be cultured Blood transfusions sulphonamide drugs and penicillin have

proved of no avail The black eschar spreads daily and cracks It separates from the subcutaneous tissue The patient dies of toxæmia and at post mortem the organs show cloudy swelling and the spleen is enlarged soft and friable

5 **Aneurysms** Aneurysms in stumps occur in two ways either through disease or injury in the stump itself or to a misfit in the artificial limb supplied

An aneurysm of a main artery in an amputation stump may occur in infected wounds It is liable to cause repeated secondary hæmorrhage As a late complication it has been seen in stumps in military surgery where multiple small missiles have injured the vessels causing an arteriovenous aneurysm As the development of aneurysm is often slow it may not be recognized for some months after amputation

Those which are due to a misfit of an artificial limb result from local pressure in an above knee stump A socket which fits well takes the weight mainly on the ischial tuberosity and there is a certain amount of flexion in the stump when the limb is fitted In this position there is really no direct weight bearing pressure over the femoral artery It is important that when the limb is fitted the stump should not be held in the hyper extended position either due to abnormality of the stump itself or to an increase in the lumbar lordosis

Aneurysms as a rule do not occur in stumps which have been fitted with modern artificial limbs but they do occur occasionally where of necessity patients have been fitted without adequate supervision and without the necessary amenities e g prisoners of war In such cases repeated trauma over a long time may damage the femoral artery and produce an aneurysm It is not only the repeated contusion of the vessel between the socket and the pubis which is an important factor but as has been pointed out by Kennedy Elliott aneurysms usually extend distally to this point and in cases where artificial limbs are suspended from the shoulders by braces the piston action of the stump in the socket may be an added factor Treatment is by excision of the affected segment of the artery This does not jeopardize the circulation of the stump which remains a useful stump

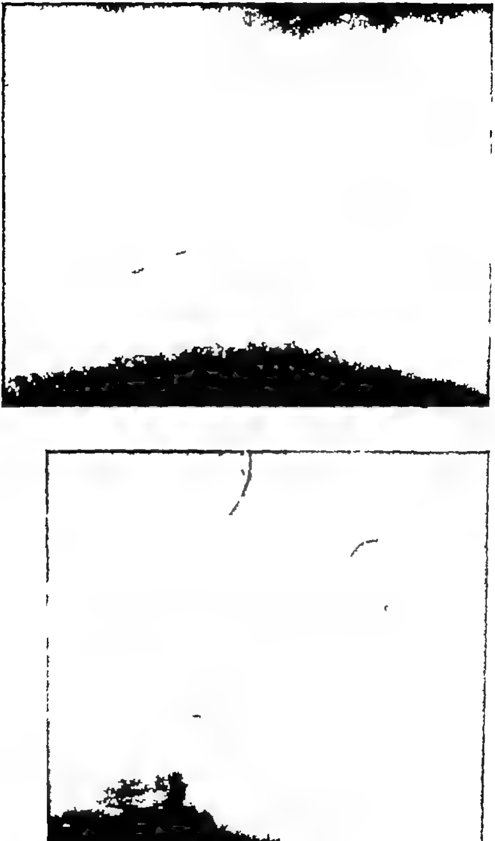
6 **Superficial Varicose Veins.** Sometimes superficial veins of the stump become thrombosed This necessitates discontinuing the wearing of the prosthesis until the condition has subsided otherwise the stump may remain unhealed for a long time after operation When conservative measures fail ligature of superficial veins usually the saphenous veins at the fossa ovalis should be considered

Lesions of Bone

Sometimes when there is infection of a stump the bone becomes involved Usually the bone is the primary source of infection But it may be secondary to an infection at a distance (see case report below) The bone responds to the infection in two different ways either by (1) necrosis with sequestrum and sinus formation or (2) proliferation of bone Both these forms of pathological change can be seen together It is usually found that the osteomyelitis is limited to 2 or 3 in (5 to 7 cm.) at the distal end of the stump In acute infections the stump becomes red and swollen owing to an associated cellulitis with the formation of pus Sometimes gas forming organisms can be cultured and there are radiological signs of gas

B F *Aged 46*

Original history rather obscure but he appears to have suffered from multiple



FIGS. 83–84 Pyogenic infection of lower dorsal spine with extensive ramifying sinuses tracking down to the outer side of an above-knee amputation. Lateral and A.P. views.

fixation abscesses (frontal region, both tibiae, left ankle) at various times prior to 1930. In that year he had a right below knee amputation, probably for osteomyelitis, and subsequently an above knee amputation for further extension of the disease.

He has had three abscesses on the outer side of the right above knee stump and the last one persisted as a chronic sinus. X-ray showed no abnormality of the femur.

When explored, the sinus tracked behind the upper end of the femur. A few days later he developed a sub-acute abscess in the left lumbar region which was incised.

Subsequent X-ray after injection of Lipiodol into both thigh and back confirmed that the thigh abscess was in fact a psoas abscess. The patient denied any previous history of back trouble (Figs. 283–84).

Culture of the pus from both sinuses showed a coagulase positive *Staph. aureus*, penicillin resistant, but sensitive to streptomycin.

Accordingly, the sinuses were irrigated with a 1 in 40 solution of streptomycin and both closed within a period of three weeks. He got up and was wearing his artificial limb, but after three weeks the sinus broke down again.

FIG. 285. Grossly irregular new bone formation with short above-knee stump. Marker indicates sinus.

FIG. 286. Complex bony spurs on lower end of tibia and fibula is a typical ring sequestrum separated from the lower end tibial stump.

Accordingly the track was opened after resection of the transverse process of L.1 and after establishing drainage at the back the sinus on the stump closed. After removal of the drainage tube the sinus on the back also healed

Periostitis

Periostitis of the bone is not uncommon. It occurs at the cut end of the bone Large proliferated thick masses of bone develop and extend along the shaft about 2 in (5 cm.) from the cut end When the infective processes subside thickening remains as evidence of chronic osteomyelitis (Fig 285) Infection at the time of amputation may give rise to this condition At times masses of new bone are found in the soft parts of the stump Infection usually stimulates the osteogenetic layer of the periosteum to proliferate and the base of the stump resembles the large irregular stem of a tree with a cauliflower-shaped end.

FIG 287 Below knee amputation. There is a small spur at the lower end of the fibula. At the time of the original injury a boot stud was blown into the soft tissues. The presence of this resulted in a persistent sinus and it had to be removed.

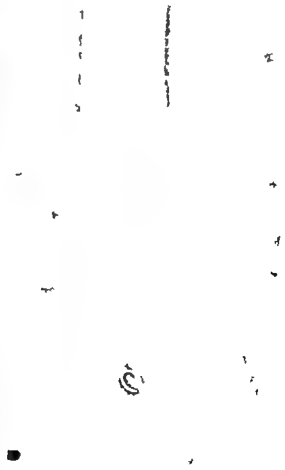


FIG 288 High below knee amputation. Ring marks Bone defect in upper end of tibia with metallic foreign b in relation to it and irregular bony spurs from lower end tibia and fibula.

Sequestrum Formation

Ring-shaped sequestra are found at the base of the stump (Fig 286) The open medullary cavity becomes infected and the resultant osteomyelitis spreads for a variable distance up the shaft of the stump The cortex gradually becomes necrosed and slowly separates from the shaft A small portion of the whole circumference may be the initial site of the condition which gives rise to a sequestrum The layers of the bone may continue to necrose and form a ring sequestrum The medullary cavity becomes obliterated by the formation of new bone which cuts it off from the site of infection When the sequestrum is removed it has a clean-cut distal end where it had been sawn through and a short or long tapering proximal end which is irregular with tapering spikes where it has separated from the living bone of the stump

Fig 289 Short above-knee amputation. Multiple foreign bodies present The bullet fragment later caused trouble and had to be removed.

Sinuses

These occur at the terminal end of the stump occasionally higher up Button like areas of granulation tissue form round the mouth of the track. At the terminal end of the stump they may be associated with a sequestrum a retained foreign body such as a swab a metallic foreign body and often a ligature (Fig 287) If the sinus does not clear up in four weeks after an amputation and there is no obvious X ray evidence of the cause it requires curetting (Figs 288 289) The removal of a stitch in the depths of the wound allows it to close rapidly Sequestra and foreign bodies should be removed by excising the whole epithelialized track together with the offending retained foreign body At the same time all excess fibrous tissue should be removed Not uncommonly a sinus may have been discharging for some time and this chronic discharge infects the skin and causes an eczematous condition This is a very incapacitating lesion obstinate to cure and prevents the patient from limb wearing for months The sinus should be dealt with as soon as possible and the eczematous skin is best treated with ultra violet light The causal organism for this localized eczema often has not been isolated in the sinus but I believe that this obstinate eczema is not infrequently caused by a local irritation of the stump

Occasionally this local eczema gives rise to a generalized eczema of the body probably caused by the absorption of toxins The patient loses his appetite and becomes febrile and after varying periods of illness exfoliation occurs Ultra violet light to the whole body has proved of value together with the administration of vitamins

Protruding Spurs of Bone

The different types of spurs have already been described These are found on most stumps They are not really complications and the great majority of spurs do not require any treatment at all In single-bone stumps the terminal and cauliflower the spiked or the conical stump variety may require treatment

Fig 290 Injury to stumps can prevent limb-wearing for long periods. Extensive bruising of an above-knee stump.

As a rule they point obliquely upwards occasionally they may be horizontal The great majority occur on the medial side, but they may be lateral. They are due to muscle traction particularly in a thigh stump the adductor group of muscles applying traction on the terminal cuff of the periosteum of the femur Complications due to spurs arise from adherent skin ulceration fractures of the spurs and localized painful areas In amputations of the upper extremity the limb fitters are satisfied if the bone is resected transversely while in the below knee amputation they require that the sharp anterior angle of the tibia should be adequately bevelled and that the fibula should be shortened for at least 1 in. (2 5 cm) If the tibia has not been bevelled and smoothed, or if tentative cuts have been made or if care has not been taken to remove the loose piece of bone at the site of the bevel, it remains partially detached and may sequestrate On the other hand, if the fibula has *not* been evenly cut and it has been crushed it develops multiple loose pieces of bone which give rise to pain and sinuses The loose bodies in these sites should be removed Ulcerations and adherent skin over spurs require excision, as described in Chapter IX together with removal of the offending spurs

Fractures of Stumps

All stumps are subject to fractures Those of the lower limbs are fractured more frequently than those of the upper

These fractures may be divided into two classes those which are usually due to direct violence and avulsion fractures e g in the lesser trochanter and those which can be described as fatigue fractures which are a result of disuse atrophy and occur as a result of decalcification and early unprotected weight bearing

Fig 291 Recent fracture of upper end of femoral shaft in an above-knee amputation. Small spur from lower end.

Fig 292. Recent comminuted fracture lower end of femoral sh in a long above-knee amputation. Unreduced and in plaster

The former class is the more frequent the patient may fall while wearing his artificial limb or as sometimes occurs when he is not wearing his artificial limb may take a false step forgetting that he is not wearing his limb Most of the recognized types of fracture occur in stumps (Fig 291 and Fig 292)

The common type in the lower extremity is a fractured neck of the femur although fractures of the shaft do occur

Fig 293. Uniting fracture of lower third of tibial stump in a long below knee amputation.

Fig 294 Above-knee amputation. Old fracture lower end of the femoral stump which has been plated.

In all fractures in stumps the accepted forms of treatment should be given consideration and the principles of fracture treatment should be adhered to (Fig 292) It should however not be forgotten that artificial limbs for an above-knee amputation and a good many for the below knee amputations are ischial bearing and have been made to measure for the individual stump

The best splint for these fractures is therefore the artificial limb if the patient already has one and if not he can be supplied with a well fitting ischial bearing pylon when the œdema has settled down Nailing the fractured neck of a femur is not only

unnecessary but may be harmful Bony union sometimes occurs in these patients without the introduction of nails If it does not occur painless fibrous union suffices

The patient need only be confined to bed until the immediate oedema and pain have subsided and therefore his confidence should be restored and he should resume walking as soon as possible

Paget's Disease of the Stump

This condition is characterized by changes in the texture of bone in the stump (Fig 293) Advanced cases show involvement of many bones but in early cases only

Fig 293 Paget s disease in an above-knee stump with a typical medial spur

the stump is involved There is a gradual bowing of the bone because of softening The weight bearing bone especially the femur in an above-knee stump, may show multiple transverse fractures

The tibia in a below knee stump may have the characteristic radiographic appearance of Paget s disease which is in direct contrast to the decalcification seen in the average stump

Bone Tumour of Stump

The distal end of the bone in a stump is not a common site for a neoplasm but the types which may occur are —

Fig 293. Uniting fracture of lower third of tibial stump in a long below knee amputation.

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Bone Tumour of Stump

The distal end of the bone in a stump is not a common site for a neoplasm but the types which may occur are —

(1) Osteoclastomata

(2) Osteogenic sarcomata

1 **Osteoclastoma.** This tumour has been seen in an above-knee amputation stump Radiograms show a soap bubble appearance while at operation the characteristic structure of a reddish brown mass has been seen

TREATMENT Re amputation

2 **Osteogenic Sarcoma.** This unfortunate recurrence has been seen in a stump the leg having previously been amputated for a spindle-celled sarcoma Five months afterwards the patient was seen with a swelling of the stump due to a recurrence of the original growth

Secondary Deposits

Secondary deposits may occur in a stump They may of course occur as a terminal phenomenon in any of the tissue layers of the stump but what is more important is that they may occur in the superficial and deep inguinal glands The tragedy here is that the preliminary surgery has been inadequate and the post-operative treatment and subsequent periodic check ups have not been frequent and thorough enough. It is the responsibility of the surgeon not only to check the suitability of the limb but to periodically re-examine his patient The following case will illustrate this point

Case Report

At the age of twenty four years the patient received a wound in the upper part of the right thigh with fracture of the femur and consequent osteomyelitis. The sinuses never healed and the scars were extensive and adherent to bone In 1943 increasing foetor of the discharge was noted and radiography showed extensive disease of the femoral shaft Granulations around a sinus that had discharged continuously for twenty five years were examined and showed definite evidence of carcinoma. The surgeon in charge recorded his conviction that the growth would be of low malignancy and aimed to preserve an adequate stump by a guillotine amputation leaving 5 in. of femur The operation was followed by early local recurrence and enlargement of the inguinal glands. The patient died within a year The histological pictures showed that the tumour was of high malignancy

Comment. In this case it seems that the surgeon shared the common misconception that it is unnecessary to take very seriously a carcinoma arising in scar tissue It is a mistaken belief that to perform the amputation is all that is necessary It is of the utmost importance to dissect out the regional lymph nodes when these are enlarged The erroneous view finds considerable support in the literature thus Harrison writing as recently as 1938 stated We have not found in the literature any instances of a carcinoma secondary to osteomyelitis in which there were distant metastases Biopsy of nearby enlarged nodes has shown only chronic lymphadenitis. Bereston and Ney (1941) however collected from the literature seven cases with proved metastases and added two of their own. It is the experience of the writer as seen from several cases reported, that the tumours may become very malignant developing rapidly infiltrating extensively and disseminating widely They must be treated as urgently and radically as any other carcinoma

This case illustrates the importance of examining not only the patient s stump but the necessity for a thorough general examination

H P Aged 58

This patient had a gunshot wound of his left leg in 191[illegible] His left foot was amputated in 1919 and he had a left below knee amputation in 192[illegible] followed by an above knee amputation in 1932

He started to complain of pain in his above knee stump which was successfully treated by periarterial sympathectomy in July 19[illegible]2 His stay in hospital was prolonged owing to his developing hæmaturia and he was transferred to a military hospital for investigation The pyelograms showed some hydronephrosis on the left but no evidence of tumour of the kidney or bladder and he was discharged from hospital

In December 19[illegible] he was re-admitted to hospital complaining of a hard lump on the outer side of his left above knee stump which was interfering with artificial limb-wearing It appeared to be fairly rapidly growing and was accordingly excised

Histological examination revealed that it was a malignant papilliform growth of epithelial origin and it was thought to be a secondary hypernephroma

In view of the previous history of hæmaturia kidney investigations were repeated Retrograde pyelogram showed a large filling defect in the renal pelvis No other secondaries were located

The nature of the condition was explained to the patient and nephrectomy offered him, but this he declined and asked for discharge from hospital to return to work.

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CHAPTER XIV

THE APPLICATION OF CHEMO- AND SERO-THERAPY TO THE SURGERY OF AMPUTATIONS

> Fifty years ago the pathway to surgery lay through the dissecting room. Today it lies through the pathological institute.
>
> [illegible]

No branch of medicine or surgery has failed to take advantage of the possibilities provided by chemotherapy, and amputation surgery naturally requires that in pre-operative as well as the post-operative therapy we should use the appropriate antibiotic agents.

It is not only of academic interest to consider the question of sepsis in amputations but of great practical importance. The Ministry of Pensions is to be congratulated on its initiative in sponsoring the investigation which has recently been completed into the medical fate of several thousands of Service amputees of the First World War. One can anticipate a completely different picture from any comparable investigation in the post-chemotherapy age.

The mortality rates during 1930–50 of all pensioners who had suffered limb wounds during the First World War was found not to differ much from those who had suffered more severe wounds and amputations. In the case of First World War pensioners who died during 1945–49 the average age at death of the leg amputees was a little lower than among a control group of pensioners who had suffered minor leg wounds only.

The investigation continued with certain types of wounds, particularly fractures of the femur that did not lead to amputation, and to consider the influence of serious sepsis, overweight and sedentary life.

A detailed analysis of the effect of sepsis was carried out. All the medical records of a third of pensioners who had received leg wounds in the First World War and who died during 1945–49 were classified into categories.

The percentage of deaths at ages under sixty in the main groups were analysed and are summarized as follows:—

	Double leg amputees	Single leg amputees	Fractured femur	Minor wound
	per cent	per cent	per cent	per cent
With serious sepsis	78.8	60.8	60.1	52.2
Without serious sepsis	63.5	55.5	45.3	44.0

The causes of death of single leg amputees, fractured femur cases and those with minor wounds were studied, and this revealed a small excess of cardiovascular disease in amputees, but when the various groups were sub-divided in accordance with the history of serious sepsis at some time in the past, a higher proportion of deaths from cardiovascular

causes e g coronary or myocardial disease was present For example among single amputees with serious sepsis almost 32 per cent of the deaths were attributed to coronary or myocardial disease compared with only 22 per cent among amputees with no record of serious sepsis, and over all the cases studied there was 5 5 per cent more deaths from these cardiac causes among the serious sepsis cases than amongst the others

These figures would seem to indicate that serious sepsis had a long term effect on those who suffered from it namely a susceptibility to die from certain forms of heart disease

The Effect of Sepsis on the Management of Amputations

When the urgency of surgery permits it the organisms in any infection should be identified and drug sensitivity established to allow of the optimum drug being used (Swabs should be taken before treatment is commenced) In potentially infected wounds in which the presence of a sensitive organism may be assumed a constantly high saturation supply of sulphonamide or antibiotic should be maintained.

Sulphonamides

In using sulphonamides therapeutically certain general principles apply and these should be carefully followed if the best results are to be achieved Since the sulphonamides are not active against all forms of bacteria the first condition is indeed sensitivity to a sulphonamide

The dosage to be employed needs also to be well understood In all serious infections an initial loading dose must be given if the organism is sensitive and subsequent or maintenance therapy follows the loading dose Maintenance therapy requires the administration of adequate doses at regular intervals

When sulphonamides are administered orally for a number of days it is of the utmost importance to ensure that the patient s fluid intake is adequate not less than 5 or 6 pints of fluid per day being taken by an adult It is also beneficial to administer concurrently such alkalies as sodium bicarbonate and sodium or potassium citrate Both the sulphonamide itself and the breakdown products of it are more soluble in alkaline urine than they are in acid urine

One of the features of sulphonamide therapy which needs careful management is the tendency for the sulphonamide to crystallize in the kidney or ureter if the urine is maintained concomitantly in a highly acid state or if the volume due to insufficient fluid intake or unusually high fluid loss is decreased Sometimes insufficient attention is paid to excessive fluid loss particularly in young children Sometimes it is difficult in seriously ill patients to force excessive fluids and if heavy doses of alkalies are given concomitantly the possibility of alkalosis must be borne in mind

The danger of crystalluria may be overcome by the joint administration of two or more sulphonamides with a greater degree of safety to the patient and with a lesser need for the administration of large doses and alkalies Based on physico-chemical facts concerning the solubilities of mixed sulphonamides, this particular mode of therapy gives highly satisfactory results One of the most valuable preparations of this kind is a mixture of sulphamerazine sulphadiazine and sulphathiazol and clinical studies have shown that the risk of crystalluria with such a combination is considerably reduced and that heavy adjuvant alkalization is not essential

The sulphonamides have largely been supplanted by antibiotics

Penicillin

Penicillin is a very potent chemotherapeutic agent which can be given intravenously intramuscularly or subcutaneously. It is very rapidly excreted and in order to ensure an adequate amount of this potent substance in the circulating blood and tissues it is necessary to inject penicillin either continuously in drip form or at regular intervals. Penicillin may also be administered orally but when given by this route only about one fifth of the amount taken is therapeutically effective (a larger dose is effective in children). Consequently the oral dosage of the antibiotic should be about five times greater than the amount used parenterally. About 80 per cent of any given dose administered orally is made inactive by the gastric juice.

Various methods of prolonging the action of penicillin have been devised. Among these may be included the injection of penicillin mixed with oil and aluminium monostearate and the introduction of the insoluble procaine salt of penicillin procaine benzyl penicillin.

The use of penicillin in oil or of procaine penicillin slows down the absorption rate of the antibiotic and also tends to maintain this slow release over a longer period thus necessitating fewer injections. In moderately serious conditions however it is always advisable to fortify such a product at the beginning of therapy by giving adequate dosage of crystalline sodium penicillin G (benzyl penicillin) for high initial blood levels of the antibiotics.

Penicillin is a non toxic substance which can be given in very high dosage and very rarely produces side effects. Occasionally however some people are extremely sensitive to the drug. They usually become sensitive to it through previous treatment with the antibiotic. Doctors and nurses can be sensitized by contact with the drug after constantly administering it. These sensitization reactions are marked by fever urticaria or dermatitis. They may appear early if sensitivity has already developed or after several days if sensitivity develops during therapy or after several months in those handling the drug. It must always be borne in mind also that in some individuals sensitivity may be due to the procaine in procaine penicillin and not to the penicillin.

Streptomycin

The introduction of streptomycin followed that of penicillin and resulted from painstaking research for an antibiotic which would be effective against Gram negative organisms. The antibiotic is produced from an actinomyces *Streptomyces griseus*. Streptomycin is relatively stable and is active against numerous Gram negative and some Gram positive organisms. It is of special value for its effect on the tubercle bacillus *Mycobacterium tuberculosis*.

The antibiotic has two main limitations its toxicity and the ease with which organisms develop resistance to it. Streptomycin is much more toxic than penicillin. It has a selective action on the eighth cranial nerve causing deafness. The neurotoxic action is less common now because smaller doses of the antibiotic are used. Nowadays for use in tuberculosis a total daily dosage of 1 g is usual. More than 2 g per day is unsafe. Generally speaking children tolerate streptomycin better than adults.

It is now well known that streptomycin resistant strains develop rapidly in the

course of treatment These strains are no longer vulnerable to treatment with the antibiotic and consequently therapy with streptomycin is ineffective in treating other patients who may subsequently be infected by the resistant strains

Streptomycin resistance is favourably influenced by the concurrent administration of para aminosalicylic acid (PAS) and/or isonicotinic acid hydrazide because streptomycin resistant strains are less likely to appear

Para-aminosalicylic Acid

Para aminosalicylic acid (PAS) is itself a milder tuberculostatic agent though its action is slower and less intense than that of streptomycin It is much less toxic than streptomycin and very much slower in producing drug resistance Para-aminosalicylic acid is administered orally it is rapidly absorbed and rapidly excreted. Dosage of about 18 g per day administered in 3-g amount six times daily is given

The solution like that of all salicylates is sickly-sweet and requires flavouring It is an advantage to change the flavouring frequently as it leads to better tolerance by the patient The drug must be given at the frequent intervals mentioned, in order to keep up an effective blood concentration To disguise its sickly-sweet taste PAS has been given in cachet form and also in tablet form, but on account of the high dosage needed this involves the swallowing of a number of tablets and cachets at frequent intervals The administration of PAS may give rise to nausea vomiting or diarrhœa and, in some cases severe gastro intestinal symptoms may occur

When the antibiotic and para-aminosalicylic acid are given together the latter as already mentioned is administered orally but the streptomycin must be given parenterally as it is quite ineffective when given by mouth

Dihydrostreptomycin which is prepared by chemical modification of the strepto mycin molecule was at first thought to be less toxic than and equally as effective as streptomycin Nowadays it is not so regarded, and it is believed to be equally toxic and perhaps even more so than streptomycin. It is occasionally used for some patients who have developed sensitivity to streptomycin.

Chloramphenicol aureomycin terramycin and other antibiotics which are broad spectrum antibiotics may be grouped together on account of their similarity Chloram phenicol was discovered in 1947 aureomycin in 1948 and terramycin in 1950

Chloramphenicol (chloromycetin) is produced from *Streptomyces venezuelæ* aureo mycin from *Streptomyces aureofaciens* and terramycin from *Streptomyces rimosus*

Chloramphenicol B P is a pure crystalline substance now synthesized.

The dosage of chloramphenicol for adults in the majority of infections is 50 to 60 mg per kg of body weight (23 to 28 mg per lb) daily in divided doses at intervals of six hours (For practical purposes this corresponds to eight to fifteen capsules every twenty four hours according to weight) This dosage should be continued until the patient becomes afebrile or until the symptoms of the disease are controlled after which 25 mg per kg daily in divided doses should be given for a further period of four to seven days

Side Effects

Administration of chloramphenicol and other broad spectrum antibiotics may be attended by nausea vomiting diarrhœa or dryness of the mouth Owing to reduction

in the oral and intestinal flora there may be an increase in the growth of non-sensitive organisms, particularly of the monilia group. This most frequently occurs in the large bowel causing a profuse growth. Thrush may develop in the mouth and a severe form of black tongue may develop. Pruritus ani may be very troublesome.

Certain *blood dyscrasias*, aplastic anaemia, thrombocytopenic purpura, granulocytopenia and pancytopenia, have been associated with the administration of chloromycetin. It is essential that adequate blood studies be made when prolonged or intermittent administration of any of the newer antibiotics is required.

One of their main advantages is the fact that they are effective when given orally.

Many properties are common to chloromycetin, aureomycin and terramycin. They are called "broad spectrum" antibiotics because of the wide range of organisms against which they are effective. None of them is effective against the tubercle bacillus. Their absorption when given orally is relatively slow and they do not need to be administered quite so frequently as is necessary with penicillin.

Recently two new antibiotics, carbomycin and erythricin, have been discovered in the United States. The latter has particular value in cases of hypersensitivity or against organisms that have acquired resistance to penicillin and other antibiotics.

Action of Antibiotics

It is now considered that the action of antibiotics can be divided under two heads (Jawetz and Gunnison, 1952). Group 1 (bactericidal): penicillin, streptomycin, bacitracin, neomycin. Group 2 (bacteriostatic): aureomycin, chloramphenicol, terramycin.

It has also been shown that combined chemotherapy can achieve more satisfactory results in some cases than if used singly, although the subject remains one of great complexity and requires elaborate and time-consuming routine bacteriological examination.

Combined therapy can be described under the heading of synergism. The definition of synergism has been described by Jawetz and Gunnison as a large increase in the rate of cure of infections beyond that obtainable by simple additive effects of the agents.

Sinuses and Ulcers in Amputation Stumps

These play a very important role in amputation surgery, and treatment can be protracted and difficult. If there are no vascular reasons why an ulcer does not heal it becomes important to ascertain the bacterial flora.

Bacteriology. The most commonly found pathogens are:—

Staph. pyogenes.
Ps. pyocyanea.
B. proteus.
B. coli (particularly after penicillin treatment) and sometimes organisms of the paracolon group.
Strep. faecalis.
Strep. pyogenes.
Doubtful pathogens: *Staph. albus.*
Diphtheroids are very often found, but it is unlikely that they play any role as pathogens.
Occasionally monilia are found, particularly after antibiotic treatment.

In the sinuses of stumps anaerobic organisms are sometimes found, such as anaerobic streptococci, bacterioides and even organisms of the clostridia group.

Certain strains of *Staph. pyogenes* are penicillin resistant. Most of these resistant

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Certain strains of *Staph pyogenes* are penicillin resistant Most of these resistant

strains are fortunately usually sensitive to chloramphenicol streptomycin, aureomycin or terramycin.

The *Ps pyocyanea* is usually sensitive to polymyxin. Polymyxin appears to be particularly effective in controlling acute pyocyanea infection. It has been used only locally as a powder (with lactose) or as an ointment in penicillin base. No toxic reactions are observed when it is used in this form. Other antibiotics have been used in powder form, ointment and fluid. Sometimes systemic treatment is added.

Drug Resistance

Drug resistant bacteria represent a major problem. What is known about the adaptability of micro-organisms is enough to caution us against any impression that *bacterial disease will soon be swept away. It is well that we should be asked to consider whether the appearance of resistant bacteria is being unnecessarily encouraged by current* methods of administering antibiotics.

Resistance to a drug may appear in many ways. Certain strains of bacteria may become resistant during the treatment—rapidly in the case of the sulphonamides. Others may be resistant from the start and these strains are becoming more common as the more sensitive strains disappear e g the gonococcus with the sulphonamides.

In the case of penicillin, certain strains of staphylococci are resistant because they produce penicillinase an enzyme which inactivates the drug. The majority of these strains are at present found in infections which arise in hospitals but the number causing "outside" infections are on the increase. Most penicillin resistant staphylococci respond to treatment by aureomycin chloramphenicol or other broad spectrum antibiotics, drugs which may be given orally and possibly are of minor toxicity. Resistance to these drugs however is already appearing and suitable combinations will have to be used more widely to combat this tendency just as streptomycin and PAS are being used to-day in the treatment of tuberculous infection.

It is clearly important for the surgeon to know if possible whether or not the organism present is sensitive to the drug he proposes to use. This is especially important should a blood-stream infection be suspected. Whatever the drug employed it is essential to give an adequate dose. If this rule is not observed treatment is inefficient and the organism may develop resistance.

Serotherapy

There is no unanimity of opinion as to the value of serotherapy in the treatment of gas gangrene and tetanus. Providing adequate precautions are taken to avoid anaphylactic complication the intelligent use of serotherapy in conjunction with chemotherapy has much to recommend it.

Authors in the First World War and during the Second World War like Mullally state that there is no definite evidence that anti-gas gangrene serum has any beneficial effect on established gas gangrene. Maes affirms that the value of serum in curing this disease is doubtful, but these authors have had little experience with chemotherapy combined with serotherapy. Since we are dealing with two deadly diseases there can be no doubt that the intelligent combination of serotherapy and chemotherapy is in the patient's interest.

Gas Gangrene. The most fertile soil for the development of gas gangrene is in muscle

injury in which there have been both extensive tissue damage and introduction of soil or other foreign material Mixed infection is almost always present at first but may later alter to a predominantly clostridial infection Anaerobic conditions and a virulent strain of clostridia are necessary for the development of clinical gas gangrene

Clostridia are sensitive to aureomycin and penicillin which has proved effective in preventing the development of gas gangrene in experimentally infected animals

Herrell states that aureomycin is definitely indicated in the treatment of gas gangrene but he believes that anti-serum should be used in conjunction with it

The Dosage of Anti gas Gangrene Serum The dosage suggested (B P 1953)

Dosage for	Prophylactic	Therapeutic
Cl welchii	10 000 units	30 000 units
Cl septicum	5 000 units	15 000 units
Cl oedematiens	10 000 units	30 000 units

E da C Afonso says that in established cases anti-gas gangrene serum should be given by the intravenous drip method 80 to 100 ml of serum in a litre of normal saline The injection should be administered after desensitization so slowly that it takes up to one and a half hours to complete Two such doses are often required N Guleke says that the amount of anti-gas gangrene serum to be injected intravenously in established cases during the first four to five days is 400 ml. J Zoissler confirms this dosage and recommends that the serum be given in continuous intravenous saline

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CHAPTER XV

PAINFUL STUMPS

Through the faint day and even in his dreams
The pain pursues him edged and merciless
Or just a blunt distress.
All night the tortured crying mysteries—
Bones muscles nerves whose names he does not know—
Are thrusting out their masked identities
Battering and breaking down the fast shut door
Beyond whose silence swings the radiant sign
That pain shall be no more "

Ada Allen *The Blind Pursuer*

Pain is a symptom, and however important it is to the patient to be given relief from his pain it is more important still that the cause of a painful stump should be accurately determined before any treatment is started

In considering the treatment of painful stumps one must bear in mind that psychological as well as physiological factors are involved The psychological element may play an insignificant part but on the other hand it may be the sole cause of the pain Distinctions between organic and functional pain are less easy to define in a painful stump than in other painful orthopædic conditions The influence of mind over matter is recognized as a force capable not only of disturbing function but also of producing organic structural changes e g joint changes secondary to hysterical postures In a world which is fraught with economic crises social maladjustment anxiety and fear the painful stump provides a fertile terrain and acts as a powerful factor in increasing the perception of pain

For this reason it is important to analyse the anatomical physiological and pathological aspects of painful stumps Only then can some form of appropriate medical and surgical treatment be considered bearing in mind that psychological guidance is needed to help the patient adjust himself to his problems

Diagnosis and treatment of this refractory symptom (which is a complication of most pathological conditions of the stump) must be based on a classification such as the following —

1 **Local Stump Pathology** (*a*) *Skin* The skin may be the site of eczema epidermoid cysts or painful ulcers which can be attributed to an ill fitting limb (*b*) *Fat and Fascia* A roll of overhanging and redundant subcutaneous tissue which may develop on the rim of the socket (*c*) *Muscle* Muscle adherent to scar tissue (Fig 290) muscle spasm. (*d*) *Nerve* A neuroma adherent to scar tissue and causing pain due to piston action (*e*) *Vessels* Ischæmia of muscles may give rise to pain choked stump —venous congestion may

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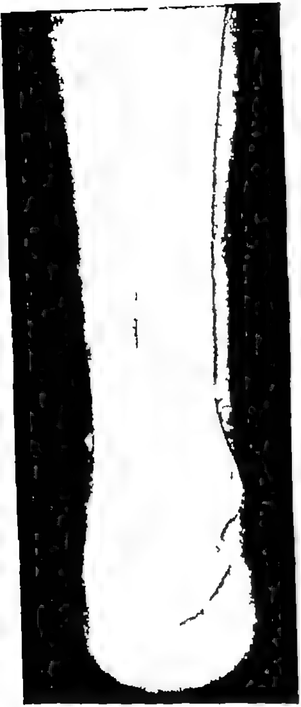

FIG 198 Pirogoff's amputation. The whole flap has been retained but bony spurs have developed on the lower end of the bone and it was necessary later to amputate at a higher level

FIG 199 Below knee amputation with metal thigh piece Owing to constriction by this the stump became so œdematous that it was impossible for the patient to remove the artificial limb This necessitated destruction of the thigh-piece by cutting Bandaging was first attempted in order to try to reduce the œdema.

for the manifestation of a painful stump Successful treatment of the primary focus often relieves the painful stump

Skin

Physiologists estimate that 50 to 200 pain points exist in 1 sq mm of skin In limbs they are more numerous at the distal end Pain is produced by tension or by

FIG. 296. Posterior view of pencil-shaped above-knee amputation with adherent scar at the back. Flexion produced puckering and pain.

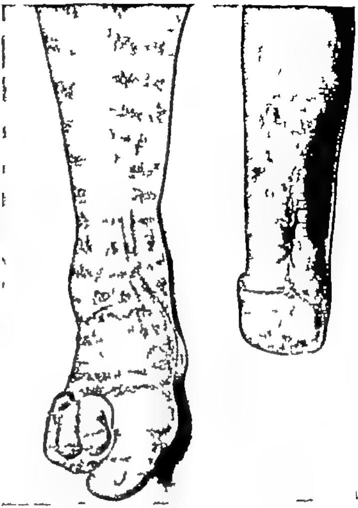

FIG 297 Pirogoff's amputation (World War I) Pain due to bony spurs. See X-ray Fig 298. Below knee amputation.

result from a badly fitting limb with varicosities of the stump (*f*) *Bone* Osteomyelitis bone abscess or spurs (Figs 297 298) Periosteum giving rise to periostitis

2 **Pain Associated with Limb-wearing** (*a*) The socket may be an unsatisfactory fit (Fig 299) (*b*) Faulty alignment of the artificial limb may cause undue pressure and pain. (*c*) The supporting appendages may be a contributory factor All these factors are intimately interwoven with those under heading (1)

3 **Remote Causes.** Pain in the stump may be due to root irritation viz. (*a*) Prolapse of the nucleus pulposus or backward displacement of a vertebral disc may produce sciatica of the stump (*b*) Osteoarthritis of the spine or joint of the stump may be a cause of painful stumps

4 **Central.** Phantom pains are discussed at length in the next chapter

5 **Psychogenic.** Economic or emotional factors may cause a neurosis which makes a stump its site of manifestation e.g hysterical deformation of stumps or a flexion contracture of the stump

II **Associated Diseases** Occasionally a peptic ulcer a tuberculous focus in the chest or elsewhere rectal disease or genito-urinary conditions may be the pathological reason

Fig 300. Below knee amputation. Unsatisfactory result A large irregular spur has developed on the lower end of the tibia where the artificial limb caused pressure resulting in considerable pain due to the formation of a bursa. This necessitated re-amputation at a higher level.

Fig 301 Amputation through the mid tarsal joint (Chopart) The patient has been walking on the end of his stump because it has been in equinus. He now walks in varus because he had developed an ulcer on a painful callosity Re-amputation below the knee

(6) Scar tissue shows little evidence histologically of nerve elements but is often associated with pain It is the state of adjacent tissue that is responsible both for the cause and the sensation of pain

The original cause of these painful stumps arises from errors of judgment on five essential surgical features of amputation (Fig 301) These are (1) a satisfactory vascular level (2) correct flap length to avoid tension and infolding (3) hæmostasis (4) separate suture of deep fascia to allow mobility of the skin, and (5) a terminal scar

Pain is ultimately due either to trauma and inflammation affecting tissue near the scar or to traction with movement on adherent nerve bulbs

chemical thermal and mechanical agents It is felt by the least specialized organ of sensation—the free nerve-ending in the stratum mucosum The extent of the painful area is appreciated from the number of fibrils stimulated its situation from central representation in the cortex and its intensity from the oscillation impulse rate The quality of pain can be elicited by the examiner but it can only be described by the subject in terms of painful association

The accurate observations of Lewis reveal that there are only two types of skin pain and these are distinct from the pain of all deep structures. Thus, momentary skin pain resembles pricking, while sustained skin pain resembles burning, which is the sensation of firmly pinching loose skin on the back of the hand General symptoms associated with skin pain include cutaneous hyperæmia, tachycardia and raised blood pressure. Locally colour change and swelling constitute the triple response produced by H-substance liberation and axon reflexes Moreover there is local lowering of the sensory threshold giving rise to the hyperæsthesia known as tenderness. Such tenderness easily becomes spontaneous pain if the tension of the injured skin rises with dependence venous or lymphatic impediment or other congesting factors

These features of painful skin are helpful clinically Thus cutaneous pain is felt precisely and recognized accurately. It may be relieved by rest elevation and release from pressure. Consideration of the actual causes of painful skin in amputees requires reference to physiological principles in connection with the pathological conditions The various conditions which may cause pain will now be discussed singly

(1) *Eczema* is common Chronic irritation from the prosthesis perspiration and impaired local nutrition account for its frequency at the tip of the stump and in the groin. Pricking from the initial erythema and vesicles is followed by burning pain when the grosser result of secondary infection follows

By further raising of tissue tension continued wearing of the artificial limb aggravates the processes causing pain. Therefore bucket and corset remodelling is necessary in recurrent cases

(2) *Roll of Fat* Intermittent pressure causes hypertrophy. The subcutaneous fibro fatty masses found in the groin in above knee amputations and in the calf in below knee amputations represent this response. As such they are physiological and painless. In the groin and in the perineum skin infections may occur as simple abscesses or follicular eczema affecting the hair follicles and sweat glands

(3) *Epidermoid cysts may become a stubborn source of pain and require modification* of the socket

(4) Similarly the *callosities* of an end bearing stump tip or of the lateral bearing bosses just below the knee are healthy responses to intermittent pressure. The stratum corneum thickens, and the pain threshold rises But greater pressure causes proliferation of the Malpighian layer and dilation of the subjacent capillaries A painful corn is produced

(5) Again, *bursæ* may be beneficial or painful responses to pressure Under the corium lymph spaces develop to provide mobile cushions at pressure points. Increased stress whether traumatic or infective gives rise to the pain of bursitis

Among these conditions, those that are painful and therefore pathological require treatment Thus conservative measures and limb fitting primarily and surgical excision secondarily is the general management (Fig 300)

During the healing stages these structures should be stretched to the optimum lengths, so that pain on early limb wearing is eliminated

There are four aids to localization of deep pain The first is clinical experience and the others are deep tenderness anatomical knowledge of the root values of muscles and Kellgren s maps.

Pain in Bone The usual bone pain of amputees is due to osteomyelitis Such pain is sometimes caused by active inflammation of bone membranes—periostitis but more often by tension within bone affecting the membrane less directly (Fig 302)

Quietly discharging sinuses associated with sequestra are not painful so long as adequate natural or artificial drainage exists Similarly the pain of muscle abscesses from retained shrapnel or contaminated sutures is arrested by relief of the tension by resolution discharge or surgical intervention When the pain in a stump is of nervous

FIG 30? Osteoperiostitis in middle third of stump of humerus.

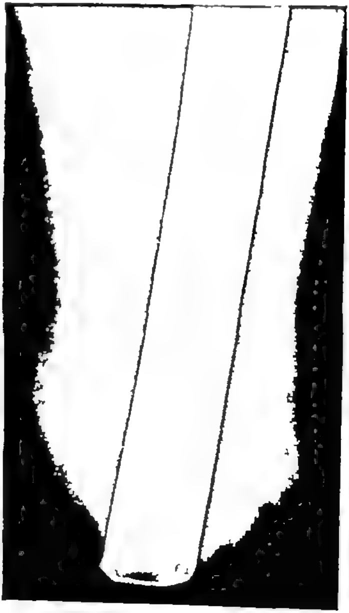

FIG 303 Above knee amputation. Extensive vascular calcification Ischæmic pain.

(7) Some terminal ulcers may be ischæmic. They may not be painful when confined to the extremity since prolonged ischæmia causes death of nerve as well as death of skin. The adjacent areas however are hyperalgesic

Associated inflammation or venous occlusion will raise tissue tension so that pain often originates from tissue innervated more proximally Thus hyperalgesia of adjacent tissue accounts for pain around ischæmic terminal ulcers. Painful terminal ulcers are often due to the push of underlying bone or to the pull of the overlying skin on the scar and the normally innervated structures lying alongside it Ulcers that are not terminal are rarely ischæmic but they are usually painful They result from the constant pressure or friction or both, of badly fitting artificial limbs

Muscles and other Deep Structures

The problems of deep pain require physiological study Again the free nerve endings in the stratum mucosum are responsible for the sensation. Subcutaneous fat has little pain sensibility but the deep fascia has more. In muscle anoxia and tension cause pain Tendon is particularly sensitive to pressure and squeezing Periosteum is very sensitive to painful stimuli but endosteum less so. Bone without its membranes is insensitive Pressure on fatigued muscle elicits true muscle pain which, like all pain originating in deep structures in limbs is a deep diffuse pain of aching quality. In further contradistinction to that of skin pain of deep-structure origin is associated with clamminess nausea bradycardia and a fall in blood pressure

Bone tendon muscles and deep fascia receive their major sensory supply from the so-called motor nerves From periarterial sympathectomy observations however it is evident that some sensory fibres pass along the vascular sheaths At the brachial and lumbo-sacral plexuses the sensory nerves from both peripheral nerve and vascular sources pass either to the somatic or sympathetic trunks. It is probable that the sensory components of the sympathetics are antidromic from the posterior root ganglia and all deep pain passes eventually through the posterior nerve roots to the thalamus and cerebral cortex

Knowledge of what is understood about the localization of deep pain is clinically essential The situation of the stimulus need not be identical with the point where it is felt This is because deep pain is subjectively felt in the skin of a segment corresponding to the segment of the deep structure and these two segments do not necessarily coincide Thus the well known disparity between the site of disease in a joint and the site of subsequent pain is explained The distribution of anginal pain in arm amputees is relevant here The sympathetic cardiac nerves spring from the eighth cervical to the fifth dorsal segments Consequently the precordial and arm areas in which heart pain is felt simply correspond in dermatomes to those segments

1 **Painful Stumps due to Flexion Contractures of Joints (Muscle or Tendon)** Occasionally it is found that extension of a below knee amputation or flexion of an above-knee stump produces pain The skin does not appear to be unusually stretched but on deeper palpation the underlying structures become taut

Exploration of such stumps shows that the fibrotendinous structures which unite the muscle to bone have become shortened Transverse division of these allows a greater degree of flexion in above-knee stumps and extension in below knee stumps

vessels in muscles often gives anomalous results and that accumulation of metabolites in both health and disease causes vaso-dilatation Clinical observation shows that physical stimuli reaching the individual threshold cause vaso-constriction of the deep vessels To reach threshold strength such stimuli must be gross enough to fire off a stream of afferent impulses sufficient to reach the central excitatory station Then efferents and/or the direct effect of the physical stimulus on vascular muscle will cause contraction Retraction will be a necessary sequel if the vessel wall is breached It is suggested therefore that diseased vessels owe their narrowing to simple organic occlusion unless a gross and sudden catastrophe complicates the pathological picture In Buerger's disease for example it is suggested that the short, sharp episodes of deterioration from major thromboses may be associated with spasm, but the mere existence of diseased vessels does not necessarily cause hypertonus in the muscles of a limb

These considerations are intended to throw light on the extremely variable results of sympathectomy in cases that so often come to amputation Though the sympathetic controls the calibre of cutaneous vessels metabolites chiefly control the calibre of muscular vessels Sympathectomy dilates the vessels of the skin and so causes a bigger pressure gradient between the deep vessels remaining patent and the skin vessels More blood therefore becomes available to nourish muscle when the greater volume flow in unit time is permitted Moreover by sympathectomy the ischæmic integument gains an improved circulation by dilated anastomoses with more proximal skin vessels Since sympathectomy is performed for progressive occlusive arterial disease such cases revert to their pre-operative state when further organic narrowing offsets the benefit of cutaneous vaso dilatation The fault lies in the pathological state of the vessels not in the anatomy of nerves

Though narrowed arteries are not painful, their effects are Ischæmia of skin first causes diminished tactile sensibility and hyperalgesia. Later with increasing asphyxia, actual anæsthesia occurs The effect on muscle is similarly pain and tenderness while the tissues survive The pain of ischæmic muscle is thought to be due to accumulated metabolites It lasts until either the nerve is rendered insensitive by continued asphyxia or blood is admitted in adequate quantity Another explanation could be that the pain-sensitive nerve-endings in structures become hypersensitive when their viability is impaired. Such hypersensitivity would account for actual pain when additional sensory stimulation which would normally cause no more than hyperalgesia occurs A rise in tissue tension from the continued presence of a tourniquet which does not control the arteries leaving bone could provide such an additional stimulus Now if all the known skin sensations may cause hyperalgesia to become frank pain is it unreasonable to expect the kinæsthetic sense to give rise to frank pain in hyperalgesic muscle ? In Raynaud's phenomena of the digits the absence of pain in the early stages is considered due to the absence of muscle There is merely hyperalgesia before numbness But the skin of the digits may experience great pain when the hyperalgesia is complicated by inflamed trophic lesions The hot phase at the end of an attack is very painful Here again the hyperalgesia which precedes the return of normal sensation, is considered responsible for the pain produced by raised tissue tension when the circulation *suddenly* returns to asphyxiated dilated damaged capillaries *Gradual* warming encourages the return of small vessel tone that can keep pace with the gradual rising of hydrostatic pressure in the capillaries and pain may thus be avoided in cold numb extremities

origin (excluding phantom pains) it may be of threefold origin (1) peripheral neuroma, (2) sympathetic (3) central.

3 **Pain in Blood vessels (Sympathetic Origin)** The part played by blood vessels in pain introduces several problems These are of such interest and importance to limb surgeons and to amputees that some detail is necessary Blood vessels possess a plexus of nerves in their adventitia and as has already been stated, probably some sensory nerves that do not synapse but travel from deep structures as stray fibres in the vascular sheath. Naked fibrils from medullated nerve terminate in both adventitia and intima Proximally the major limb vessels derive their sympathetic fibres directly from the sympathetic ganglia More distally the peripheral nerves supply the vessels It is likely that all vascular afferents enter the cord via the posterior root ganglia In the production of pain, sensory endings in the vessels themselves do not seem to play the major part Most pain is objective in that the subject is usually made aware of some factor that increases the sensation or reduces the harmful process responsible for the pain. Actual or threatened destruction of skin causes pain

The response to destruction of vascular tissue is involuntary spasm of the vessel, which may produce either pain in the vessel or pain due to muscle ischaemia (Fig 303) This is partially relieved by cessation of muscle activity External agents such as ligatures and needles cause some pain while internal agents such as sclerosing solutions do not seem to do so unless they reach the extravascular tissue through the capillaries or some surgical error Embolism in a limb at rest is painful. The physiological response to adequate stimulation is reflex spasm Muscle normally contracts when adequate physical, nervous or hormonal stimuli change its environment This is true even of the muscular coats of the vessels and accordingly external physical agents such as trauma and cold affecting the adventitial endings and internal agents such as emboli and thrombi affecting the intimal endings may cause contraction of the vessels thus causing muscle ischaemia and pain.

When trauma causes a segment of artery to undergo spasm the blood supply to the limb may be improved by excision of that segment by sympathetic block, or by spinal anaesthesia The reflex arc is broken The sympathetic is the afferent side of the arc Apparently the adventitial plexuses carry only true sympathetic (that is non medullated) fibres so that when spasm occurs in a limb vessel after adequate sympathectomy it must be due to the direct effect of noxious stimuli on the vessel itself

Painful Stumps of Normal Appearance It is noteworthy that painful above-knee amputation stumps which, in spite of abstaining from limb-wearing and other palliative measures could not tolerate any prosthesis have yielded to excision of a segment of the femoral vein or the femoral artery or both. Excision of the femoral vessels does not impair the circulation and there is complete relief from pain with resumption of limb-wearing

A patient has been known, during amputation following recent sympathectomy for Buerger s disease to develop spasm lasting several minutes after the release of a Samway s tourniquet Cold and trauma we maintain, may directly affect the denervated vessels The importance of the nervous mechanism in intact vessels subject to trauma and to cold is of course undisputed

How big a part do sympathetic afferents play in governing the calibre of deep vessels in health and disease? Experiment shows that sympathetic stimulation of normal

picture is found in motor nerve lesions such as poliomyelitis. It is striking that chiefly below knee and to some extent below-elbow, amputations give rise to this condition. It is infrequent in amputations proximal to these joints. The common factor is muscle atrophy. In below knee amputations the muscles with the exception of the popliteus have no action on the joint and, therefore undergo disuse atrophy. But in above knee stumps the rectus femoris in front, the adductors to the inner side and the hamstrings behind all exercise the hip-joint. In below knee stumps therefore it is probable that the atrophy of vessels associated with wasted muscle accounts for the ischæmic extremity seen in these cases. Coldness and blueness result from the impoverished blood supply and the reduced hæmoglobin that accompanies capillary stasis. Pain follows when either permeability of the capillaries gives rise to intercellular tension or when trophic skin changes occur. Moreover congestion is an added factor from the local venous insufficiency due to muscle inactivity. Sympathectomy has a place in treatment by allowing dilatation of the skin arterioles. If the atrophy of the muscles and their vessels is complete and clinical tests such as reflex heating and direct sympathetic block correct the circulation sympathectomy may be performed. Enhanced anastomosis with the proximal skin will then benefit the extremity. On the other hand the venous circulation still remains

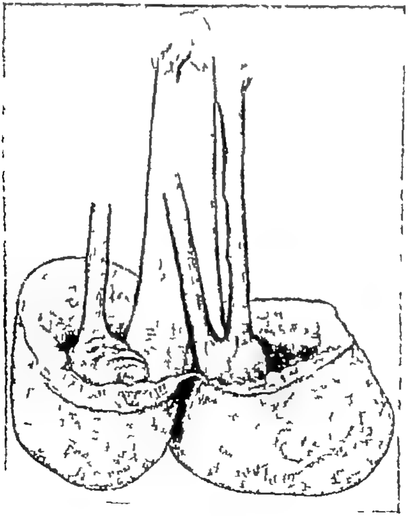

FIG. 306. Amputated segment of stump showing invaginated skin and large neuromata attached to the skin.

The conception of hyperalgesia normally occurring in impaired nerve may also be applied to the sensitive zone that surrounds the anæsthetic centre of peripheral nerve lesions It may explain what happens to the thin individual who having sat with crossed legs long enough to induce a sciatic palsy uncrosses his legs If he then walks the hyperalgesia preceding the return of normal sensation gives rise to spontaneous pain It is suggested that this results from the extra stimulation of kinæsthetic endings by posture and motion

Of vascular considerations there remains the peculiar condition of *cold and discoloured painful stumps* This disorder is not uncommon in amputees and a similarly distressing

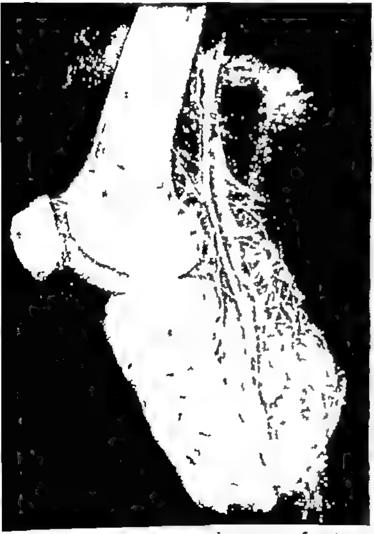

FIG 304 Lateral arteriogram and venogram of a stump which shows that the vascularity of the amputated segment is sufficiently good to outline in detail the smaller vessels in the region of the patella, yet the subcutaneous vessels have not filled.

FIG 305 Antero-posterior view of arteriogram and venogram of the same stump shows that the subcutaneous arches are well outlined, yet the vessels do not fill in spite of the great pressure under which the opaque material has been injected Unable to wear his artificial limb because of pain.

FIG 306. Gun-shot wound of left shoulder with amputation of left arm Painful scar at the back of shoulder and loss of contour Special protective prosthesis provided.
[*Ann. Roy Coll. Surg Engl.*

in the direction of the nerve trunk They are contained in a capsule of the abundant connective tissue which develops in all amputation stumps The neuroma may become attached to skin muscle or bone If a stump has healed by primary intention the amount of cicatricial tissue will be minimal On the other hand if the stump has been infected the amount of cicatricial tissue will be great the neuroma is large and it will be so embedded in the cicatrix that it may be difficult to distinguish it from the cicatrix itself (Fig 307) It is this type of neuroma that is the cause of the majority of painful stumps though it

defective and consequently cases of failure are sometimes seen when dependence and prosthetic constriction cause circulatory stasis (Figs 304 305)

4 **The Painful Stump due to an Amputation Neuroma.** This subject has perplexed surgeons for centuries Some authors state that the incidence of painful neuromata in amputation stumps is as high as 72 per cent (Shosberg) while others give figures which are between 25 and 30 per cent Herrmann and Gibbs report a series of cases in which this complication is as low as 6 per cent This wide variation in different series of cases is due firstly to the pathological indication which determines the primary amputation.

Fig 307 Subcapital amputation of right humerus with adherent scarring and painful neuromata.

If amputations are performed because of inflammation and infection as occurs in war the possibility of a painful neuroma becomes higher On the other hand, the technique of amputation is important handling the nerve stump injecting it and traumatizing it invariably lead to a higher percentage of painful neuromata Again it must be realized that fortunately the opportunities for assessing large numbers of amputation stumps are not numerous and the judgment of individual observers varies

An amputation neuroma develops at the terminal end of the nerve stump (Fig 306) Its size varies according to the diameter of the nerve and according to the tissue in which it is left to implant itself At first pink in colour it then becomes grey and eventually is a white lustreless structure usually club-shaped and surrounded by a capsule and a sheath. Histologically it consists of nerve fibres which have proliferated from the ends of the neurofibrils The neurofibrils take an irregular course and often become *loop-shaped*

state that the growth of the neurofibrils of the severed nerves takes place in tissue which anatomically and physiologically, is exactly *the same as, or very similar to that in* which the nerve-endings of the amputated nerve were normally situated It is of great importance that the growing neurofibrils should be able to proceed without interference from the section surface of the nerve to a point where they can make connections with the muscle fibres When they are implanted into a muscle they are able to pick up anatomical connections with the muscle fibre to which they become intimately attached After the grafting of mixed nerves into muscles the neurofibrils end in the muscle fibres *with the result that the motor and sensory fibres make intimate connections with the* muscle tissue The muscle fibres apparently have an attraction for the neurofibrils (exert a tropism) without distinction of central or peripheral nature or function

Painful Stumps as a Sequel to Osteo-arthritis of the Spine

Spinal osteo-arthritis may give rise to pain in the stump as it does elsewhere Pain may be caused by bad limb fitting over a long period *Arthritis of the spine especially* of the lumbar spine may accompany a below knee or more usually an above-knee amputation It is not possible to say whether this is primary or consequential to the amputation Osteo-arthritis which is frequently polyarticular may have been aggravated by the amputation As with other spinal diseases it may remain purely a local painful condition manifested by a diminished range of movement and radiological evidence of osteo arthritis. On the other hand, it frequently causes reflex pain in the stump by *reflex irritation It is important* to bear this in mind in clinical examination and to radiograph the spine in all painful stumps

Treatment is by abstention for the time being from limb wearing with appropriate conservative measures such as rest and physical treatment e g heat and short wave diathermy

Painful Stumps due to Root Irritation, e g., a Prolapsed Intervertebral Disc

This type of painful stump may be produced by nerve root irritation as a result of protrusion of a displaced lumbar intervertebral disc Pain in the back, in the stump and even phantom pains, make the differential diagnosis difficult

If the physical signs of scoliosis, when viewed with the patient standing or when he bends forward or sideways are aggravated by one or other movement, a disc lesion should be borne in mind Gluteal wasting is usual in amputations and is not a reliable sign, while wasting of all muscles in the stump is of no significance The straight leg test in a below knee amputation or the stretching of the sciatic nerve by flexion of the above-knee stump should always be performed and an X ray examination is necessary to exclude other possibilities, e.g caries osteo arthritis of the spine or as in the following case the rare condition of an aneurysm involving the radicals of the sciatic nerve Pain with weight bearing is common and may be relieved by abstention from limb wearing for about a fortnight it is aggravated by early resumption of weight-bearing

Treatment of such lesions is essentially conservative few cases require operation

Case Report

W P aged 34 years, admitted to another hospital in April, 1946 with a

must be admitted that a small neuroma can be attached to bone or skin and therefore cause pain on movement and pressure (Fig 308)

When a neuroma forms it still keeps the fundamental function of nerve tissue i e., transmission of nervous impulses Stimuli are picked up from the cicatrix and transmitted to the brain by sensory or sympathetic channels Here they evoke sensations which may be painful On the other hand, the stimuli may never reach the brain and cause only a local reflex arc with tonic or clonic muscular contractions in the stump evidenced as jactitation (jerking) It should be remembered that muscle is richly supplied with both sensory and motor fibres whilst pain-causing impulses can be transmitted from the terminal neuroma and become intensified when the scar or cicatrix is pulled upon or compressed either by friction piston action or by any other form of trauma It is well known that sensory and motor nerves also contain sympathetic fibres and that sympathetic fibres may reach the cortex by circuitous routes I have frequently sectioned large mixed nerves known to be trigger points for pain without avail The patients have still continued to complain of pain but—more important—have still exhibited the same trophic disturbances which they had shown previously These cases have occasionally been relieved by sympathectomy

The Prevention of an Amputation Neuroma. Odier at the beginning of the nineteenth century first described enlargements or swellings which developed on the distal end of a proximal segment of a peripheral nerve after partial or complete division He started to inject nerves with absolute alcohol and sectioned them just below the injected area. There is no doubt now that this is harmful. Nerves should not be crushed or ligated The perineural flap method as suggested by Corner the swing-door or reverse V operation and the crush and tie procedure have all been shown by Huber and Lewis, in careful studies to be unsuccessful in preventing neuroma formation.

One should not tie a nerve trunk in with an artery for this is a direct cause of painful convalescence

There have been numerous other attempts to prevent the formation of amputation neuroma The end to-end anastomosis of two sectioned nerves which was practised by Leriche and Fontaine gave poor results and was abandoned Laewen tried refrigeration with solid carbon dioxide while Hedri treated the nerve after section by thermocautery and again by injecting the nerve stump with alcohol and formol—also unsuccessfully Good results are said to have been obtained by Poth and Bravo-Fernandez who treated the cut nerve with multiple injections of 10 per cent solution of tannic acid or 2 per cent solution of gentian violet These solutions inhibit the rapid production of neurofibrils and consequently the formation of neuroma Herrmann and Gibbs, on the other hand, ligated the nerve stump with a non-absorbable material such as a steel thread the theory being that the neuroma does not develop because the perineurium then surrounds the neurofibrils which are strangled by the steel thread thus inhibiting the growth of the nerve

Dogliotti White and Boldrey implanted the principal nerves in an amputation stump into the bone marrow through a canal running into the cortex of the bone hoping to inhibit the formation of the amputation neuroma.

Of all these numerous methods none has proved worth while

More recently Stephen Teneff and Rosso of Turin experimented on rabbits implanting the principal nerves between muscle fibres adjacent to the amputation site They

Painful Stumps due to Arthritis of Joints

This is common in weight bearing joints and is not always attributable to amputations Painful stumps due to arthritic joints should be diagnosed by complete clinical examination diminution of the range of movement crepitus and X ray

Conservative treatment is usually successful If operative measures have to be undertaken arthroplasty usually of the hip joint is the method of choice An arthrodesis is not recommended as it will alter the whole limb fitting situation and will aggravate an already difficult problem

In osteo arthritis of the knee the patella can be excised with benefit if the disease is patella femoral while in osteo-arthritis of the hip arthroplasty often results in the patient being able to resume limb wearing

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history that he had fallen from a scaffold fourteen days previously He had a swelling in the right groin which had been diagnosed as a contusion On the day of admission he had a sudden pain at the back of his right knee

On examination the right leg was cold and pulseless The popliteal and anterior and posterior tibial pulses were absent A swelling was present in the right groin and pulsation of the common femoral artery could be detected in the upper portion of the swelling, but was absent in the lower part of the swelling The diagnosis of embolus at the bifurcation of the common femoral artery was made Operation was performed under spinal anæsthesia. The common femoral vessels were exposed and after excising the femoral artery a mass of thrombus was evacuated followed by organized clot This was succeeded by a steady flow of blood from the distal end of the profunda collaterals. The common iliac artery was then exposed transperitoneally and tapes passed round it The femoral artery was again exposed and the incision in the vessel sutured. The pulsation returned to the point in the femoral artery where it had been present before, but the distal segment remained pulseless and in spasm. The abdomen was closed after the tapes had been removed Pulsation had still not returned in the femoral artery after this was done, and the wound in the leg was closed

On April 22nd 1946 a line of demarcation just below the knee appeared and the calf and foot were gangrenous below this point On that day amputation was performed above the knee Three days later the patient developed gas gangrene The wound was opened, the muscles were found to be widely gangrenous and were therefore excised. The adductor group was particularly affected. The leg was re-amputated and the wound was sutured very loosely

The next day the abdominal wound and the scrotum suddenly became swollen Multiple small incisions in the anterior abdominal wall, scrotum and thighs were made in order to release the gas.

Slow recovery ensued and on June 16th 1946 the patient was discharged on crutches with the wound almost healed. When seen a month later the stump was satisfactory He was re-admitted to hospital in May 1952, complaining of pain in the small of the back during the previous five months. The usual location had been over the lumbar region, but the pain had occasionally passed round the front of the groin and into the inguinal region The testicle was never retracted and no difficulty of micturition had been experienced

On examination, the movements of the spine were found to be restricted in all directions, and flexion of the stump reproduced the pain (stretching of the sciatic nerve) complained of originally A diagnosis was made of sciatica of the stump, and complete rest was ordered The patient improved slightly but his sciatic pain continued A plaster of Paris jacket was applied and this gave him temporary relief from the sciatic pain. On the third day in plaster he collapsed while lying in bed and it was obvious that he was suffering from internal hæmorrhage The plaster was removed and the patient given a blood transfusion. When he had sufficiently recovered a laparotomy was performed

On opening the peritoneum an extensive retroperitoneal hæmatoma was found extending from the mesentery of the sigmoid colon up the paracolic gutter beneath the spleen and pancreas. The site of the hæmorrhage was not determined and the peritoneum was closed as it was decided that further interference would prove immediately fatal. His condition deteriorated and he died the following day

At post mortem a false aneurysm of his aorta was found which had been eroding the lumbar vertebra, and had exposed the roots of the sciatic nerve

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CHAPTER XVI

PHANTOM LIMBS AND SOME OBSCURE SEQUELÆ OF AMPUTATIONS

> The mind is its own place and in itself
> Can make a heav n of Hell a hell of Heav n "
>
> MILTON *Paradise Lost*

AFTER the amputation of an extremity, a high proportion of patients experience sensations which they ascribe to the absent limb In the majority of cases these sensations are more vivid immediately after amputation then as time passes, they tend gradually to fade from consciousness In some cases (probably about 10 per cent) symptoms become so severe that the patient is more keenly aware of the phantom limb than he was of his normal extremity He may be so distracted by the unbearable intensity of this pain which he describes as cramping twisting or squeezing in character as to lose his social usefulness.

Children with congenital absence of limbs never complain of phantom pains but I have noticed that many children with amputations while they do not complain of phantom pains are none the less aware of their phantom limbs

Although the wound which necessitated an amputation may have been producing a foul-smelling discharge for years the patient with a phantom ' limb will never complain that it smells

Phantom limb hallucinations have certain common characteristics which may be summarized according to Weir Mitchell under the following headings —

(1) A continuous feeling of the amputated limb
(2) Sensations of pain and of motion frequently localized in it
(3) Sensations of an approach of the distal parts of the amputated extremity to the proximal stump
(4) The limb has become smaller than the real one and has in fact become very small
(5) The position of the limb may correspond to that just before its loss
(6) The position may be comfortable or cramped and uncomfortable
(7) The temperature seems different from that of the retained limb
(8) Both voluntary and involuntary movements are possible
(9) Wounds present in the actual limb appear in the phantom
(10) The phantom does not appear until some time after the amputation

Theories as to Origin

Neuro-muscular Theory (Gillis). In spite of the amputation even if as high as the hip joint the motor cells in cord and higher centres are intact and have undergone little or no injury The cells of the sensory neurons in the ganglia on the posterior roots of the spinal nerves are also practically uninjured If shock is minimal, recovery of the nerve cells should be rapid

If the sensory nerve fibres in the stump are stimulated some will cause a reflex response in muscles still remaining whilst others will be carried up to the centres in the thalamus and the cerebral cortex where the appropriate sensations are experienced, i.e., touch heat, cold pain etc

The patterns in the cerebral cortex formed as a result of sensations, extero-ceptive and proprio-ceptive are still the same and *therefore when the many nerve impulses from the proximal ends of the severed nerve reach the same parts of the cerebral cortex the* response must be identical As these impulses before the operation arose from all parts of the limb the patient has the hallucination that the whole limb is still there and to it he refers all the sensations arising from the stimulation of the ends of the nerves in the stump These patterns were formed in early childhood when by 'trial and error limbs gradually came under control

In the case of amputation of the breasts or any other involuntary organ no patterns are *formed because there is no voluntary movement*

In the intact body there is a continuous stream of impulses bombarding the cortex from the sensory nerve-endings in the muscles tendons and ligaments of the body This bombardment of both sides of the sensory cortex is balanced and both sides are in a state of neuro muscular equilibrium When a limb is amputated a neuro-muscular imbalance immediately results This will play a greater part in future motor activity of the individual and will influence his phantom limb

It is the readjustment of the remaining muscles of the body to the altered state which now throws additional strain on the sensory cortex of the cerebrum and makes the previously existing state of equilibrium so liable to be upset It is this constant effort of the central activity to maintain this equilibrium between the continuous stream of impulses from the remaining part of the body which makes a phantom limb an ever present possibility and brings the awareness of the absent member to consciousness

The capacity of the individual sensorium to readjust itself to the new conditions of the body and its new environment after an amputation may or may not give rise to the varied manifestations of a phantom limb The physical alterations and mental fluctuations in subsequent life will act as stimuli and as predisposing factors causing a central release which will result in pain in the phantom All amputations are associated in the mind of the individual with a varying degree of pain This is not dependent on whether pain has preceded the amputation or not *Further the individual will react to this pain* according to the degree of subconscious pain which already exists in his sensorium and this phantom pain will be further modified according to his level in the phylogenetic scale It has been noticed that highly intelligent sensitive patients are more prone to phantom pain than the more phlegmatic unimaginative individuals

It has been observed that wearing an artificial limb is often a comfort to the patient with a phantom limb and tight bandaging at night when his phantom pain becomes aggravated, relieves this pain In fact many individuals often hold on firmly to their stumps with both hands in order to relieve the pain This pressure has the effect of restoring temporarily the balance of the impulses which impinge on the sensorium and so relieves the pain. *These observations influence treatment* It is a useful form of treatment to make a plaster sheath for these stumps, in which the patient can sleep The patient himself often doubts the reality of his own sensations Fear of accusation of insanity makes him disinclined to talk about his symptoms and he prefers to hide

them until he can no longer bear them This may result in gross mental disturbance and the sufferer of a phantom limb is often regarded as psychotic

The patient who shows the slightest indication of phantom pains should be told that we believe he gets these pains—that they are very real to him and since he has lost his limb from his point of view there is no foundation for the stimulus now A determined attempt should be made to convince the patient that the phantom pains will cease With this conviction established the pains often disappear

Cerebral theory, suggested by A Pick who considers that the body image is the keystone because phantoms are not experienced in congenital defects or injuries of early childhood since the responsive amputated part has never been represented in the body image

Schilder places main emphasis on body image because phantom limbs are absent in slowly progressive losses such as freezing joint tuberculosis and progressive diseases of bone and joints The gradually diminishing size of the phantom limb is explained by the gradually dwindling body image of the adult which is supposedly replaced by the more resistant one of the child

It has been observed that the phantom limb disappears after injury to the posterior central convolution or injury to the parietal region of the brain This may point to the cerebral characteristics of the phantom The narcissistic inability to renounce the integrity of the body and the impossibility of adaptation to a sudden defect are not sufficient explanation of a phantom since it may occur without such a defect as in a brachial plexus lesion while phantom like sensations may occur in hemiplegics

Peripheral theory proposed by Pitres who said that the sensation originates chiefly from excitation of the nerve-endings in the scar Pitres Souques and Poisot concluded that the disappearance of the phantom after anæsthetization of the stump and its return when the anesthesia was no longer effective indicated that the genesis of phantom pain was peripheral When the phantom had disappeared it could be recalled by peripheral stimuli Peripheral stimuli may increase perception if it is already present

The essential factor in all cases is the relationship of the phantom limb to sensory stimulation of the stump The ætiological importance of sensory stimulation can be illustrated by cases in which tapping over the tibia produced evidence of this part of the phantom while otherwise the foot appeared to begin at the stump

I believe from a study of my cases that peripheral sensory stimulation of some kind not necessarily pain is a significant factor in the formation of this phantom limb and that an important role should be assigned to such stimulation. By placing the main emphasis on the peripheral factor I do not deny the significance of cerebral emotional mechanisms in the formation of the phantom In fact the phantom sensation must be brought about by a process involving the entire nervous system beginning at first peripherally and eventually becoming a fixed image in the cerebral cortex

Peripheral stimulation from the stump is eventually carried into the same regions which would be reached by peripheral stimulation from the limb if this were still present If one may so put it the stimuli encounter their old engrams in the place where the body image is localized (Schilder)

It is no pure chance that its localization coincides to a large extent with the highest cortical sensory centres The primitive stimuli emanating from the periphery are the raw material for the evolution of the phantom Phantoms are not as a rule observed

after amputation of the breast or penis facial disfigurement or loss of other organs This is not in agreement with psychological theories. The narcissistic inability to renounce the integrity of the body should be even more pronounced after amputation of the breast for example than after loss of the extremities

It seems that the engrams of easily movable parts of the body can be more readily reproduced than those of less easily movable parts Cortical sensory centres of the movable parts of the body are carriers of the body image whilst afferent sensory stimuli of these centres give rise to the phantom limb which is a peculiar partial hallucination Peripheral stimuli are the *pin pricks* which the phantom requires in order to emerge into consciousness

The Treatment of Phantom limb Pains

It is essential to establish an accurate clinical diagnosis before any attempt is made to treat the condition and for this purpose phantom pain can be divided into two types —

(a) That associated with positive clinical findings i e,

(1) Neuroma,
(2) Adherent scar
(3) Painful tender scar
(4) Tender spur
(5) General conditions of ill health i e the presence of disease or other symptoms.

(b) Phantom pain in which there is no discoverable pathology in the stump itself

It is the latter type of phantom pain which concerns us here and it is this particular type of pain which is so difficult to eliminate Invariably the patient whose pain falls into this category has already a certain degree of central fixation and for this reason it is absolutely essential that he should be allowed to give his history and a description of his condition without any assistance from the questioner He should be encouraged to talk freely

When the diagnosis has been established the treatment consists of

(1) Non-operative and
(2) Operative measures

The former should be pursued zealously because it is well known that if conservative measures fail the likelihood of cure by operative methods is very small.

The Conservative Treatment. Physiotherapy which should at first include firm bandaging by day and night the application of ultra violet radiation up to the second degree dose short wave diathermy anodal galvanism wax baths or ultra-sonic therapy When there is a palpable tender neuroma and there has been no response to treatment then percussion therapy may be considered Lack of response to any of these methods may necessitate local injection of 1 per cent novacaine into the neuroma, or even into that section of the sympathetic chain which influences the nerve segment involved in the phantom pain, e g the cervical block for the upper extremity and the splanchnic block for the lower extremity In some cases of painful stump relief of the symptoms may be obtained by the injection of 1 or 2 per cent novocaine into and around the painful neuromata. This is however only a temporary measure and a more prolonged effect in cases which respond to novocaine may be obtained by infiltration with 2 per cent benzocaine and 40 per cent. urethane in distilled water a combination which I have found most useful over a period of years This solution causes initially a severe burning

sensation and the technique best adopted is first to infiltrate the area around the neuroma with novocaine and then without removing the needle inject the benzocaine urethane solution Benzocaine being practically insoluble in water is precipitated in micro crystalline form by the watery tissue fluids as the urethane is absorbed, thus forming an efficient depot anæsthetic with an effect lasting from six days up to several weeks In the cases of phantom limbs where the neuromata are very painful and sensitive it is preferable to carry out this infiltration procedure under pentothal anæsthesia

Treatment by Repeated Percussion In 1940 Ritchie Russell described a method of treating painful amputation stumps and phantom limbs by repeated percussion to the stump neuromata He considered that the regenerating nerve fibres which form neuro mata in an amputation stump might be even more vulnerable to a minor trauma than were normal nerves and nerve-endings

The basis for this theory was that conduction in a mixed nerve was easily interrupted by repeated pressure without causing pain If a painful neuroma could easily be hammered its nerve fibres would gradually degenerate and be replaced by fibrous tissue

No method has yet been found however to prevent a nerve that has been severed from forming a neuroma and as some of these painful stumps have tender neuromata which on pressure cause pain referred to the phantom these tender neuromata act as trigger points

In this form of therapy therefore it is important to locate the tender neuromata as accurately as possible it is not however always easy to do so In an above knee stump they lie behind and above the level of the end of the bone In a below knee stump they may not only be behind but also in front Commonly a tender neuroma is felt subcu taneously in front of the stump and is due to the lateral fibrils from the severed popliteal nerve

In an above-elbow stump the neuromata are situated on the inner aspect and can frequently be felt as a nodular swelling high in the axilla

After amputation of the arm neuromata of the median and ulnar nerves frequently occur These nerves should be resected as high as possible because they are then away from any pressure by the neuroma In my experience a painful phantom is much less severe in amputations through the forearm These tender nodules are localized and are covered by skin, subcutaneous tissue and frequently by muscles If squeezed, they produce paræsthesia in the phantom or marked local pain

If the neuroma is very tender a sphygmomanometer cuff can be applied to the proximal part of the stump and inflated so that the blood supply to the stump is suffi ciently occluded.

This observation was made in 1320 by Henri de Mondeville who found that as a result of the anoxæmia the neuromata become less sensitive They can then be percussed Percussion is performed by means of an applicator which consists of a wooden rod about 6 in (15 cm) long One end of the rod is placed on the nerve and the other end is percussed. A suitable type of rod is the end of a crutch with a rubber cap over it This prevents damage to the skin and to some extent diminishes the sound of tapping The neuroma is percussed with a moderate degree of force and for as long a period as is possible without undue discomfort If the patient has sensations referred to the phantom or stump these confirm that the applicator is suitably located on the neuroma

At first percussion is confined to a few minutes but later the duration is increased until the patient can stand about twenty minutes. The cuff may be removed after the percussion, and it is found in practice that this is no longer necessary after the first few treatments. Treatment may be repeated three or four times daily.

An electrical vibrator is sometimes used instead of the mallet. This has the advantage that it can be applied over a large area and the frequency can be varied. The patient is taught to use both types of applicator himself.

To obtain the best possible results it is advisable to co-operate with a psychiatrist. Full consultation on the best approach to treatment is necessary if it is becoming apparent that physiotherapy is unlikely to succeed. Different types of patients may need a different psychiatric approach and handling.

It is essential to take these patients into one's confidence. One should sedate them with sodium phenobarbitone or sodium amytal as necessary. In addition the mind of the patient should be kept occupied by suitable occupational therapy and he should be encouraged to concentrate on his work and hobbies. In certain patients of unstable personality, when the psychic elements appear to predominate, hypnosis and even electro-convulsant therapy may have to be considered.

The rationale of electro-convulsant therapy in cases of phantom pains is to over stimulate and discharge electrically the pattern of neural electrical behaviour. On the whole this has not proved very successful. Sometimes however it does break up the cerebral thought (and pain) pattern.

Operative treatment must be avoided as long as possible and then the relatively minor procedures only such as excision of a neuroma or scar division of nerves or re-amputation, should be considered.

In the past many operations have been practised in an attempt to eliminate phantom pains e g neurectomy rhizotomy sympathectomy antero lateral chordotomy and even excision of parts of the parietal lobe of the cerebral cortex.

All these operations met with little success so that surgeons turned their minds to pre-frontal leucotomy and lobotomy. It is doubtful if such procedures are justifiable as they do not in themselves abolish the perception of pain but merely produce changes in the personality of the individual. The change is mostly one of lessened drive and initiative. Cases in which the patient is becoming very tense and "screwed up" about the pain, i e neurosis with tension and distress following the appearance of the phantom, are likely to benefit from leucotomy if other methods fail. Their attitude to the pain is altered and this is a relief to the patients. The psychological reaction is less and they are more stoical and philosophical about it. They are less likely to become violent to themselves or to others on account of the pain. The pain, however will persist. It is therefore questionable whether surgeons are justified in performing operations which can only dull the patient's mind and do not in actual fact eliminate the phantom pains.

Recent work suggests that the division of the dorsal columns of the tracts of Goll and Burdach at an appropriate level of the spinal cord may meet with success. These tracts are concerned with posture but to date we have no surgical operative procedure that can successfully eliminate the patient's pain. Operative procedures like chordotomy meet with a certain degree of success for the removal of pain in the actual stump but the patients still complain that their phantom sensations remain unaltered.

There is no doubt that phantom pains of some duration develop cerebral fixation

but there are probably pathways other than the spino-thalamic tract by which fixation occurs e.g the posterior columns

Causalgia

This terrible malady was first described by Weir Mitchell after the American Civil War, and since that time it has borne the name of *causalgia*, derived from two Greek words meaning heat and pain on account of the intense burning pain which is its most characteristic symptom

No satisfactory explanation has so far been given for the distribution of the disease which affects mostly the median and the posterior tibial nerves Leriche has described this condition thus Causalgia is the response of a certain temperament to an ordinary injury ' This observation is not valid causalgia has an organic basis although it is known that certain patients with causalgia may elaborate their symptoms This is shown in the anatomical and physiological discussion which follows

Certain facts however, are known , the frequency with which it occurs in partial division of the nerve, the excessive formation of scar tissue and in the case of amputations, that it most commonly occurs with amputations of the fingers in particular the terminal phalanges Stopford in 1917 thus analysed this condition after studying a series of cases that it occurs very frequently (1) when a nerve is partly divided, (2) in cases where there is excessive scar tissue and (3) in amputations commonly in the fingers and more particularly the terminal phalanges

Anatomical and Physiological. It is extremely unlikely that the pain can be simply the result of irritation of the fibres subserving common sensibility because it is not of the neuralgic type and it is quite different from that due to irritation of a purely sensory nerve Anatomically the median and internal popliteal nerves differ from other nerves of the limbs in containing a proportionately larger number of vasomotor fibres for the supply of the superficial palmar and plantar arches with their respective digital vessels These arteries as is to be expected from their relation to the circulation of the limbs receive a very much richer nerve supply than the larger and more proximal vessels The suggestion that the pain is the result of some interference with vasomotor control is supported by its bursting character and the throbbing which occurs It increases when the part is dependent or moved. The surface temperature is usually elevated, and there is an accompanying hyperæmia of the skin

Irritation of the vaso-constrictor fibres would cause constriction of the vessels which would be apparent by blanching of the skin and a lowered surface temperature Instead in causalgia there is hyperæmia, and a raised temperature, and the condition may be relieved by the application of cold which reflexly causes constriction of super ficial vessels Clearly therefore everything points to the presence of vaso-dilatation but the mechanism by which this is induced is difficult to understand Three possibilities suggest themselves —

(1) *Paralysis of Vaso-constrictor Fibres* It is known that after division of the sciatic nerve the vaso-dilators degenerate more slowly and retain their irritability longer than do the vaso-constrictors When it is remembered that causalgia frequently persists for many months and that the essential pathological lesion is partial division with intra neural sclerosis this possibility therefore appears to be very doubtful

(2) *Direct Irritation of Vaso-dilator Fibres* Opposed to this supposition is the fact

At first percussion is confined to a few minutes but later the duration is increased until the patient can stand about twenty minutes The cuff may be removed after the percussion, and it is found in practice that this is no longer necessary after the first few treatments Treatment may be repeated three or four times daily

An electrical vibrator is sometimes used instead of the mallet This has the advantage that it can be applied over a large area and the frequency can be varied The patient is taught to use both types of applicator himself

To obtain the best possible results it is advisable to co-operate with a psychiatrist Full consultation on the best approach to treatment is necessary if it is becoming apparent that physiotherapy is unlikely to succeed Different types of patients may need a different psychiatric approach and handling

It is essential to take these patients into one s confidence One should sedate them with sodium phenobarbitone or sodium amytal as necessary In addition the mind of the patient should be kept occupied by suitable occupational therapy and he should be encouraged to concentrate on his work and hobbies In certain patients of unstable personality when the psychic elements appear to predominate hypnosis and even electro-convulsant therapy may have to be considered

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Operative treatment must be avoided as long as possible and then the relatively minor procedures only such as excision of a neuroma or scar division of nerves or re amputation should be considered

In the past many operations have been practised in an attempt to eliminate phantom pains e.g neurectomy rhizotomy sympathectomy antero-lateral chordotomy and even excision of parts of the parietal lobe of the cerebral cortex

All these operations met with little success so that surgeons turned their minds to pre frontal leucotomy and lobotomy it is doubtful if such procedures are justifiable as they do not in themselves abolish the perception of pain but merely produce changes in the personality of the individual The change is mostly one of lessened drive and initiative Cases in which the patient is becoming very tense and screwed up about the pain i e neurosis with tension and distress following the appearance of the phantom, are likely to benefit from leucotomy if other methods fail Their attitude to the pain is altered and this is a relief to the patients The psychological reaction is less and they are more stoical and philosophical about it They are less likely to become violent to them selves or to others on account of the pain The pain however will persist It is therefore questionable whether surgeons are justified in performing operations which can only dull the patient s mind and do not in actual fact eliminate the phantom pains

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There is no doubt that phantom pains of some duration develop cerebral fixation

Clinical From the study of cases it seems that the condition occurs mainly in the median and sciatic nerves It is quite common to find tenderness even to slight pressure on the inner or outer borders of the foot in a sciatic lesion as a residual symptom This may be persistent and sufficient to incapacitate a man from getting about in spite of the fact that the muscles may have regained a great deal of their power

Tenderness as in the case of amputations is associated with a slightly glossy skin or simple hyperæmia and the patient usually complains of a throbbing pain in the part which is made worse by the warmth and dependency of the limb

One should beware of dismissing such a case as hysterical It is not uncommon to obtain a history of pain which might suggest causalgia and which lasts for a few days or even weeks and then passes off but it is more common to find the development of profound motor and sensory symptoms

In these cases the excessive fibrosis has usually strangled the nerve to such an extent that it produces a picture of complete division The usual clinical symptom is bursting or burning pain in the affected part the nerve is generally swollen or doughy and the temperature of the skin is higher than on the normal side The pain is usually persistent and intractable and in its severest form sufficient to render the patient extremely irritable It may even drive him to suicide It is made worse by heat movement excitement or the dependent position The only thing which appears to give relief is cold Occasionally a patient has presented himself with a note from his doctor suggesting the possibility of suppuration The manifestations of nerve irritation in the case of the fingers i e the glossy skin hyperidrosis hyperæmia and bone and joint decalcification may all be seen

Treatment

Severe pain is an urgent symptom. Agonizing pain wears the patient down mentally and physically In treating it it is important to remember that the pathological condition which gives rise to it is partial or complete division of the nerve with increasing perineural and intraneural fibrosis In the case of partial division of the nerve the following principles should be borne in mind (*a*) careful separation of all adhesions round the nerve (*b*) complete clearance of all perineural fibrosis (*c*) complete hæmostasis to reduce the resultant scar as much as possible and lastly (*d*) the nerve must be embedded and protected from recurrent adhesions

In the case of amputations re amputation should be discouraged particularly in the fingers If the amputation has been of the terminal phalanges a favourable result can often be obtained by making small dorsal incisions proximal to the amputation dissecting out the digital nerves and resecting a portion of them In the worst cases major surgery has been advocated Following on a preliminary positive block, sympathectomy has been advocated by Ross and others In my hands this has not been successful Chordotomy has sometimes been performed but has proved a failure Injections of novocaine or alcohol into the affected nerve have been recommended as a form of treatment but they should be used with care Considerable temporary relief can sometimes be given by maintaining the limb elevated on pillows with the part wrapped in lint and kept moist with some evaporating lotion Further benefit is obtained by keeping the patient free from external disturbance Causalgia still remains a nightmare

that irritation of both constrictor and dilator fibres would cause vaso-constriction. Therefore to uphold this contention it would be necessary to have either paralysis of the vaso constrictors associated with irritation of the dilators or the irritation would have to be selective on the dilators. Obviously such conditions are not possible nor do the histological findings support them.

(3) *Reflex Vaso-dilatation.* This suggestion appears more reasonable because it does not require the supposition that the irritation is selective in its action on the component fibres of the nerve nor does it necessarily depend upon the presence or absence of vaso dilatation. It seems rational to suppose that as a protective and defensive mechanism irritation will cause a vaso-dilator effect.

The increased severity of the pain which results from the mere prospect of movement or excitement can be understood and appreciated more clearly since by the above supposition it can be explained as a physical depressor effect.

It is necessary to refer briefly to two theories which have been advanced as an explanation of causalgia. The first suggests that the pain is the result of irritation of the peri arterial sympathetic plexus and is not directly due to injury of the nerve trunk. This theory is largely based upon the erroneous anatomical supposition that sympathetic nerves are supplied to the vessels high up and pass proximally as a peri arterial plexus to supply the branches to the coats of the vessels. This has been disproved by the work of Kramer, Todd, Potts and Langley, who show that the arteries receive sympathetic fibres at irregular intervals down the limb from fairly constant branches of the nerve trunks.

The second theory has been suggested by the presence of an unusually large nutrient artery to both the sciatic and median nerves, the branches being the comes nervi ischiadici in the former and the median branch of the anterior interosseous artery in the latter. It is suggested that in causalgia these vessels are implicated and that the blood supply of the nerves is seriously reduced. In the greater proportion of median injuries the lesion is proximal to the entrance of its nutrient vessel either in the axilla or upper arm, or in the case of causalgia following posterior tibial nerve injuries, the lesion is also proximal to the entrance of the comes nervi ischiadici.

Pathological. From the appearance at operation and from microscopic examinations of excised portions of nerve it is evident that two constant conditions are found: first, partial division, and, second, intraneural fibrosis. It is customary during surgical procedure to find the nerve firmly adherent to the surrounding structures with a variable amount of perineural scar tissue extending some distance both proximally and distally. It is extremely difficult to clear away the extraneural fibrosis and the nerve or nerve bulb is seen to be swollen and very firm. There is increased vascularity as is evidenced by the colour of the nerve and the aggravating oozing which occurs during neurolysis from the divided capillaries which can be seen entering the nerve from the scar. On microscopic examination it is found that the nerve bundles are widely separated by excessive fibrous tissue by which they are compressed. The sheaths of the bundles in close relation to the nerve fibres are ruptured, and the scar tissue gains entrance to and invades, the interior of the nerve bundles. The nerve fibres are strangled by the sclerotic tissue but the number so affected will depend upon the time which has elapsed between the reception of the wound and the excision of a piece of nerve for examination. The newly formed fibrous tissue does not differ from scar tissue elsewhere nor does the condition vary from that found on histological examination of other injured nerves.

Fig 309 Hysterical flexion contracture of above-knee stump. This patient cannot straighten her leg even with great pressure applied by herself with her crutch.

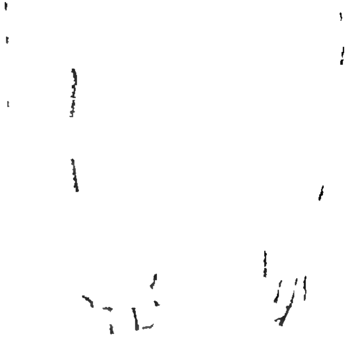

Fig 311 Gross lymphœdema of hand and forearm induced by constriction of sleeve of nightgown.

Fig 310 Lymphœdema of right hand and forearm Note line of constriction which has been self inflicted in arm. Plaster applied to left elbow

Hysterical Deformities of Stumps

Functional affections in amputation may give rise to severe flexion contractures of the hip and the knee These are usually of psychogenic origin The patients have muscle spasm but no actual disease of the stump and muscle paralysis cannot be demonstrated. *The flexion contracture may be so extreme and so difficult to correct that the patients* may be unable to obtain relief by their own active physical attempts (see Fig 309) Organic contractures can follow hysterical contractures

The hysterical simulation of disease of the joint is characterized by an elaboration and prolongation of the symptoms and by absence of physical signs of disease Pain is *not* a pronounced symptom These cases are difficult to cure and failure to do so results in the patient being unable to wear an artificial limb Frequently a consideration of financial compensation for the injury which necessitated the amputation lies in the back ground But *motives other than financial gain* real or imagined can sometimes lead to hysterical contractions The soldat blesse is in a power position which is sometimes not easily given up in order to face life s impossibilities instead of being ministered to by angels as an interesting and privileged invalid Fear of being unable to use the prosthesis is often an unconscious factor For this reason and because there may be other back ground *factors not at once apparent a full psychiatric survey is necessary* in cases in which a hysterical element is suspected

Sometimes hysterical symptoms are produced unconsciously to defend the psyche against an even less bearable life situation than the loss of limb or inability to wear an artificial limb Such cases need very careful handling when the attempt is made to *surmount their hysterical condition* *Hysterical œdema of the amputated limb* and also hysterical swelling of the contra lateral limb due to fear of bilateral amputation is met with Hysterical swelling of limbs is a condition which is well known and is often symbolic Mallinson and Scott reported on a series of cases in naval ratings (1944 in the *B M J*) Two examples in my experience are here given —

Miss E M P Aged 27

In 1944 following an encounter with a man with a hatchet she developed swelling of both hands the left being worse than the right

There were various neurological disturbances of the left arm and the diagnosis was made hysterical paresis of the left arm with œdema of unknown origin

The condition persisted intermittently until 1947 during which time she had much physical and psychological therapy

In 1947 the left hand being normal the right hand and arm began to swell in a similar fashion Extensive investigations were again undertaken and it was possible to reduce the swelling to some extent by elevation in plaster

However in 1949 it was established at this time at any rate that her swelling was self induced by constricting the arm just above the biceps (Fig 310) The hand at this time was elephantine cold cyanotic sweating and almost immobile and hung from her shoulder wrapped in cotton wool like an unwanted appendage (Fig 311)

The swelling was considerably reduced by physical measures though not entirely abolished and an attempt at rehabilitation was partly successful (Fig 312)

When she was discharged she was using her right hand and was looking forward to taking up a resident occupation (Fig 313)

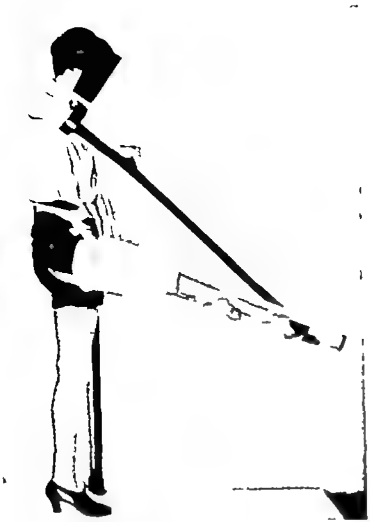

FIG 309 Hysterical flexion contracture of above knee stump This patient cannot straighten her leg even with great pressure applied by herself with her crutch.

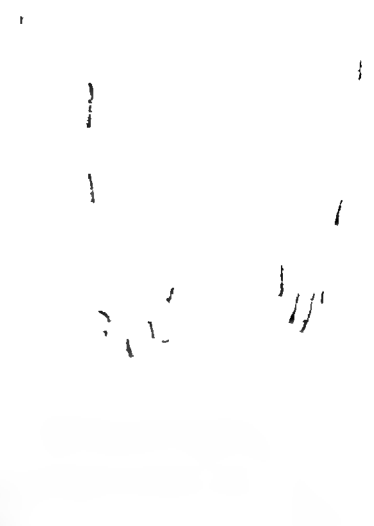

FIG 311 Gross lymphœdema of hand and forearm induced by constriction of sleeve of nightgown.

FIG 310 Lymphœdema of right hand and forearm. Note line of constriction which has been self inflicted in arm. Plaster applied to left elbow

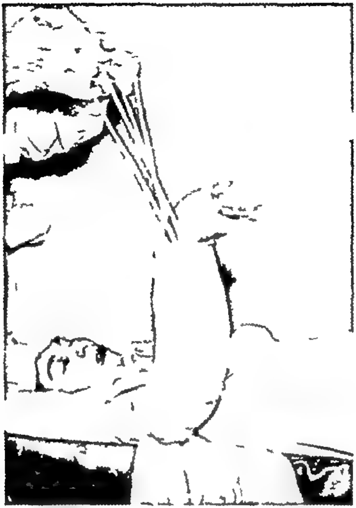

FIG 312. Plaster also applied to right hand and forearm to try to induce postural drainage

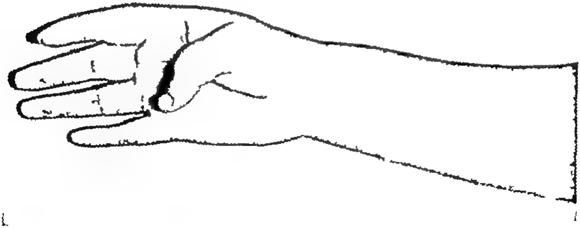

FIG 313 Result after treatment

Nurse J R Aged 38

1943. Lysol burn back of left hand

Wound did not heal and skin grafts did not take

Subsequently developed swelling of hand and finger contractures

In 1946 an operation was performed to relieve œdema (? Kondoleon) This was unsuccessful

In 1947 a below-elbow amputation was performed but the stump never healed

FIG. 314. Amputation of left arm which had been treated by a series of unfortunate re-amputations. Patient inducing constriction of right hand and arm by means of axillary straps.

FIG 315 Œdematous hand of the above patient

FIG 312. Plaster also applied to right hand and forearm to try to induce postural drainage.

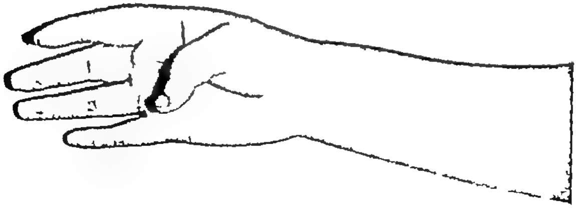

FIG. 313 Result after treatment

inflicted wounds of the stump These may take two forms (1) when the stump is in the healing process, or (2) when the stump is already healed

They occur more commonly however when the stump is healed because the bandages are then left off and the stump does not receive the constant supervision of the nursing staff

It is incredible that otherwise highly intelligent people will produce self inflicted wounds There must always however be a basic abnormal psychological condition in such cases and they need psychiatric assessment and help The true malingerer is not normal His conduct is reprehensible and anti-social but nevertheless he is a psychopathic personality Normal people do not malinger (Though one must admit that a lot of people will evade responsibilities by exploiting illness—this is a moral, not a medical surgical or psychiatric matter)

The extent to which patients will sometimes go to inflict injury on their stumps is incredible as the following case will demonstrate A patient who had been a prisoner of war in Japan and who had suffered a below knee amputation was admitted to hospital The end of the stump showed a peculiar raspberry like swelling which bled at regular intervals When the patient was first seen he was pale and anæmic and it was obvious that this hæmorrhage had taken place over a lengthy period Investigation of his blood condition did not reveal any significant abnormality It was necessary to transfuse this patient several times before his blood picture could be brought to anything like normal

It was then decided to re-amputate the stump at a higher level and remove the swelling The patient also had a double inguinal hernia and as he had been a prisoner of war and appeared very anxious to get home as soon as possible it was decided to repair the double inguinal hernia at the same time The operations were therefore performed his stump was re-amputated and radical cure of each inguinal hernia carried out The stump healed perfectly and the left inguinal hernia also healed well but the right inguinal hernia continued to bleed

During a ward round it was noticed that the patient had blood under his finger nails and had obviously been interfering with his right inguinal incision The patient was taken to the operating theatre and anæsthetized and a plaster spica was applied so that the groins were completely covered. The wounds then healed perfectly limb-fitting ensued and the patient remained well for seven years Later he returned to hospital with peculiar skin lesions in the neighbourhood of his umbilicus He was surprised to see that the surgeon who had originally treated him was still at the hospital and he asked to be discharged at once

Treatment in such cases should start with psychiatric investigation, and may have to be followed along psychiatric lines in addition to appropriate measures to bring about healing of the self inflicted wounds in the skin or damage to the stump

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and six months later an above-elbow amputation was done This was very slow to heal but the wound finally closed in 1948 after the arm had been encased in plaster which was not removable

She was fitted with an artificial arm in February 1949

Two months later the right hand began to swell and the œdema spread up to the elbow

In 1951 investigations included salt balance test and phlebograms, but no abnormalities were detected beyond decalcification of the bones, suggestive of Sudeck's atrophy

The hand was swollen with easily compressible œdema extending up to 4 in. below the elbow The fingers were cold moist, cyanotic and movement was negligible

Elevation produced a temporary and incomplete improvement

The patient was resentful distant in manner and unco-operative in treatment.

A presumptive diagnosis of "hysterical hand" was made (Figs. 314 315)

After two months as in patient during which elevation and physiotherapy and elementary psychotherapy were carried out an improvement occurred almost overnight and within one month she was discharged with minimal œdema of the fingers and movement restored to about 70 per cent of normal. Her personality altered she was cheerful and looking forward to a course of training as a commercial artist

A very careful physical examination of the whole patient is necessary in this condition Examination under an anæsthetic of the joint involved gives great assistance Under pentothal anæsthesia one can often demonstrate that the stump is flaccid and the joint not involved.

Treatment When the diagnosis is certain and all organic lesions have been eliminated the injury should be viewed from a compensation angle and treatment should be started. These patients usually possess an element of mental instability Hysterical subjects are usually dull mentally and immature When they have "converted" hysterically they often display a bland indifference to their surgical plight ; their attitude is "Here's my symptom it's up to you to cure it doctor"

The settlement of the pension for amputation is a necessary prelude to any surgical or psychiatric therapy i e the removal of the gain motive

In this type of case when a flexion contracture exists in the knee in an amputation below the knee amputation above the knee will be followed by a flexion contracture at the hip-joint Complete change of environment along with psychiatric treatment is helpful Physiotherapy and occupational therapy should play a part in the general treatment

Jactitating Stumps. In a below knee stump jactitation or clonic movement involves not only the below knee section but the whole segment , and in the case of an above-knee stump the whole limb jactitates Isolated units in the stump involving one or two muscles undergo twitching This is not a "jactitating stump" but is more in the nature of an excessive irritability of a single muscle or group of muscles

Treatment A search for the cause of the jactitation should be made Psychiatric examination and if necessary psychotherapy may prove useful Sedation sod. phenobarbitone gr 1 b d., over a long period is often of assistance

Artefacts of Stumps. Patients who have had amputations sometimes produce self

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Cine radiography in Artificial Limb Fitting

In 1897 Dr John Macintyre produced a pseudo-cine radiographic record by taking a series of ordinary skiagrams of the frog s leg in different positions and arranging them in order to show the movements These were afterwards transferred to a cinematographic film Since then three distinct methods have been adopted (1) The original synthetic method of Macintyre (2) The direct method in which a band of film is exposed direct to X rays in a rapid series of exposures, as in ordinary radiography (This method has been successfully developed in recent years by Van de Maele of Brussels and Barclay, of Oxford) (3) The indirect method where a motion picture record is made of the fluorescent screen image

Russell Reynolds has worked on the indirect method since 1921 later he coined the word cine-radiography To this pioneer must be given most of the credit for the development of this particular method into a true cinematographic recording The indirect method is the only practical method available for study to-day

Cine radiographic films can be studied indefinitely and repeated examinations within reason are not detrimental to the health of the patient or examiner The strips of film recording these examinations can be kept with the case notes and may accompany the patient anywhere Their value lies in a permanent record of movements which can be used for (1) diagnosis (2) comparison with former records to watch the effect of treatment or the progress of a pathological condition (3) research (as in cases where it is impossible to visualize a whole physiological process or for instance the behaviour of a stump within an artificial limb socket) and (4) teaching purposes The immediate advantages of a record of what can be seen on the fluorescent screen are that the film will permit a leisurely and repeatable study of movement and that the action can be stopped at any stage for a closer scrutiny of any particular image which may arouse interest

Even with the employment of the best artificial limbs there remain some cases in which the wearer of an appliance complains of pain in his stump It is here that cine radiography opens up a completely new field of investigation The cause of the pain may be obvious It may be due to ulceration to a bursitis or to a septic epidermoid cyst On the other hand there may be nothing to see or even to feel and the diagnosis may not be apparent The painful stump may be relieved by leaving off the limb in which case the limb is probably to blame In order to understand why the pain is either initiated or aggravated while the limb is being worn one must know the behaviour of an ideal stump in a well fitting limb Hitherto we have relied on experience and clinical judgment in the diagnosis and treatment of the causes of a painful stump

Cine radiography provides us with a new and valuable method of investigation into the combined behaviour of the stump and prosthesis in any movement which the patient is able to make I have recently been carrying out such examinations on both painless and painful stumps fitted with various types of artificial limbs Study of such films shows that a mass of useful information may be obtained and that the interaction of stump and prosthesis is often unexpected and complicated

In the usual method of investigation lead wires are fastened securely in various positions to the skin of the stump before the artificial limb is put on When the films are projected the wires show clearly the degree of movement between the skin and the

CHAPTER XVII

NOTES ON THE RADIOGRAPHY OF STUMPS

Clinical diagnosis is an art and the mastery of an art has no end; you can always be a better diagnostician.

GLENDENING

WHILE radiography is undoubtedly of great value in the diagnosis and treatment of surgical conditions which necessitate amputation the fact is too often overlooked that it can also be of great value in the diagnosis and treatment of the pathological complications of amputation stumps

The radiography of stumps requires special consideration in order to obtain the best results. The following recommendations should prove of value —

(1) Pathological stumps are invariably dressed with greasy dressings all greasy and opaque dressings e.g elastoplast should be removed

(2) As stumps often prove difficult to steady and may even jactitate immobilization with a compression band and sandbags is usually necessary

(3) Patients with painful stumps invariably find comfort in flexion contractures, and it is necessary to straighten a flexed limb before radiography begins

(4) Antero posterior and lateral films should be taken as a routine. With below knee stumps oblique views are sometimes helpful. The patient can usually be rotated into position. In above-knee amputations a true lateral view is possible if the film is placed at the outer side of the stump with the leg in the antero posterior position. The other leg should then be raised and the tube centred on the stump. With very short stumps a satisfactory lateral view cannot often be obtained. Here an oblique view will be found useful

When radiographing a stump for suspected fracture e g after a fall the whole joint at the proximal end of the stump must be included on the films. When a fracture occurs above it is almost always in relation to the joint and not in the shaft of the stump

Radiographic Technique Non-screen films have been found to give good bone definition and can be used with success with three exceptions —

(1) In thick muscular stumps

(2) In a very short above knee stump and

(3) Where complete immobilization is impracticable

In these cases screens are advisable. Exposure will obviously vary and depend upon the unit in use, and the current supply

At Roehampton the following factors are used with non screen films at a *F.F.D of 30 in —

(1) Below knee *K.V 45–50 M.A.S 60–75

(2) Above knee *K.V 50–55 M.A.S 70–85

* F.F.D = focal film distance; K.V = kilo voltage M.A.S. = milliampere seconds.

are required but also that other experimental types of artificial limb with various stumps should be tried The problem is not one which can be rapidly solved, as a certain time must elapse before effects become apparent

It is apparent that the treatment of an amputation does not end with a surgical operation There are unfortunately pathological sequelæ in stumps some inherent in the disease which has necessitated amputation and some conditions which are directly attributable to mechanical defects in artificial limbs

Clinical investigation and radiography are of importance for the accurate diagnosis and treatment of such conditions

It is the responsibility of the surgeon to decide whether a patient should wear a limb or not and it is his responsibility to decide whether a limb is satisfactory or not

A few of the indications for radiography are given below

These can be summarized as follows clinical and prosthetic. The clinical conditions that occur can be those referred to bony or soft tissue in which there is either a history of trauma pain symptoms of articular disease or the presence of sinuses infections or possible spur formation

Prosthetic Here it is important to decide primarily whether a limb is end bearing or proximal bearing In end bearing limbs the alignment and weight bearing areas should be investigated while in proximal bearing limbs the alignment the coincidence of natural and artificial joints and the problem of whether or not a limb is tuber bearing may be helpfully seen on X ray films All congenital abnormalities of the limbs and amputations in children require radiography for their accurate assessment

The following case is an example of the value of radiography and ancillary methods of investigation in deciding upon the management of a particular case

E S *Age* 31 *Female*

At the age of three years the left leg was first noticed to be longer than the right and for five years she was regarded as a case of poliomyelitis of the right leg until the development of a hæmangiomatous area on the dorsum of the left foot Further areas developed, later they began to ulcerate and in 1930 (aged sixteen) a left above knee amputation was performed for uncontrolled hæmorrhage Several years later a purple area developed at the end of the stump which began to ulcerate and bleed An arteriogram in 1949 confirmed a hæmangiomatous condition almost certainly with multiple arterio venous communications involving the lower 3 in. of her amputation stump " and in 1950 a re-amputation was performed Within a few months, however a purple raised area developed again at the stump end which ulcerated when she wore the artificial limb

Present Condition

The stump is warmer than the right thigh There is a thrill and continuous murmur in the groin and upper stump Branham s phenomenon is present (pulse drops from 88 to 68 on occlusion) Cardiac output was 12 litres per minute Electro-cardiogram was normal

Radiograph of the chest showed no increased heart size and aortogram was performed (Fig 316)

It will be seen from this that there is an extensive arteriovenous fistula high up in the thigh, particularly in the region of the great trochanter Re-amputation would be a hazardous procedure and this patient was therefore advised not to wear her artificial limb but to get about on crutches most of the time

prosthesis, and indicate also the amount of stretching of the tissues which results from piston action If the stump is painful the patient is provided with a pain indicator so arranged that by pressing a button at the moment when pain occurs an opaque pointer or point of light appears beside the shadow of the limb on the fluorescent screen and is simultaneously photographed It is then possible to determine the moment at which pain occurs and to see the movement of the stump within the prosthesis which produces it.

As might be expected the relative movement of stump and prosthesis varies considerably depending on the length of the stump the type of amputation and the design of the artificial limb Often piston action is a prominent feature and it is instructive to compare the relative movement of the bone and soft tissue in the stump Sometimes piston action is replaced or added to by antero posterior lateral or rotary movement There are types of socket with a short femoral stump in which the bone actually tends to rise out of the prosthesis when weight bearing

The following two histories give a few facts which I have observed in a series of cases and some of these seem paradoxical

Case 1164a

This case shows two outstanding features —

(1) That the axis of the artificial limb and the axis of the stump correspond very poorly and

(2) That there is a great deal of piston action The patient complained of much pain in his stump when walking After realignment of the artificial limb the axis of the stump and that of the artificial limb were found to synchronize much better the piston action was eliminated and the patient said he was comfortable It is noteworthy here that the piston action and the poor axial relation between the stump and the artificial limb co-existed

Case 1105a

This patient complained of a painful below knee stump. There was no obvious neuroma to be felt. The stump was not tender Cine radiography showed that there was good co-axial correspondence between the stump and the artificial limb Piston action was practically absent. This indicated that the artificial limb was satisfactory and that the fault lay in the stump itself The patient was subjected to an operation for division of the popliteal nerves. The artificial limb was not altered. He was discharged relieved.

Comment. The above are two of the many cases that have been analysed and successfully treated along these lines

Points noted and studied include —

(1) The varying axes of stump and different prosthesis

(2) The varying relations between the artificial joint and the natural joint in short below knee and below-elbow amputations during movement

(3) The relation of the direction of painful and non painful spurs to the movement of the stump in the prosthesis

Active research is being continued both to obtain more data on the behaviour of a stump in an artificial limb and also to determine the most suitable type of stump and prosthesis in amputations at various levels

For this purpose it is clear not only that more examinations of existing prostheses

Fig 31 Comminuted fracture of lower third of left humerus. Incomplete bony union. Large metallic foreign body in axilla.

Fig 318. Fractured shaft is now united and neoarthrosis has been produced at the junction of the middle and lower third of humerus below fracture level.

FIG 316 Aortogram showing arteriovenous communications in a left above-knee stump. The external iliac artery is larger on that side the superficial femoral attenuated and the shunts extend to a level above the trochanter

A few additional examples which serve to illustrate the value of radiography in the diagnosis and treatment of pathological conditions in stumps are appended below (Figs 317–332)

Fig. 317 Comminuted fracture of lower third of left humerus. Incomplete bony union. Large metallic foreign body in axilla.

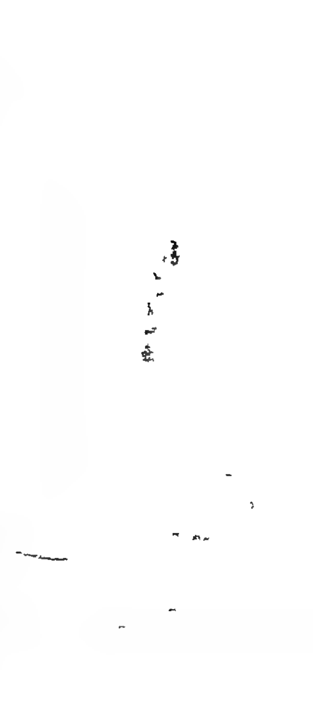

Fig. 318 Fractured shaft is now united and neoarthrosis has be produced at the junction of the middle and lower third of t humerus below fracture level.

Fig 319 Neoarthrosis lower third of humerus. The upper part of the lower component is sequestrating

Fig 320. Neoarthrosis of shaft of humerus. Continuity has been restored by parallel columns of new bone

Fig 3 1 High above-knee amputation. Osteotomy has been performed through the subtrochanteric region and the bone fragments have fused There is dislocation of the deformed femoral head and upward displacement of the whole bony mass.

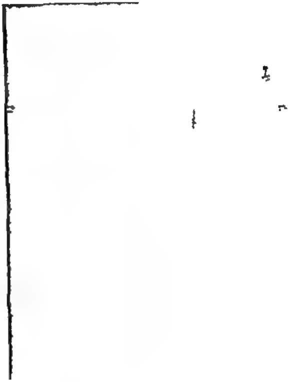

Fig 322. Subtrochanteric amputation of hip S abducted and flexed This forms a useful ledge for B a tilting table.

Fig 319 Neoarthrosis lower third of humerus. The upper part of the lower component is sequestrating

Fig 320 Neoarthrosis of shaft of humerus. Continuity has been restored by parallel columns of new bone.

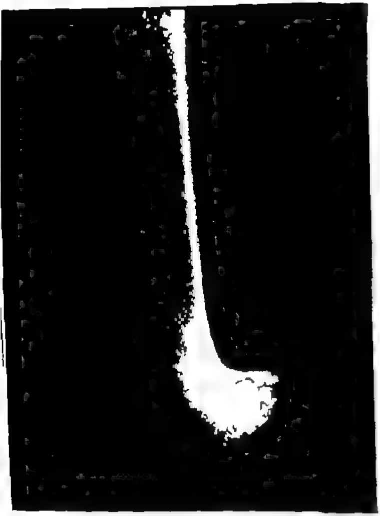

FIG 325 Stokes-Gritti amputation The patella has fused at a considerable angle to the line of the shaft This is an unsatisfactory amputation as it is not easy to fit an end bearing prosthesis.

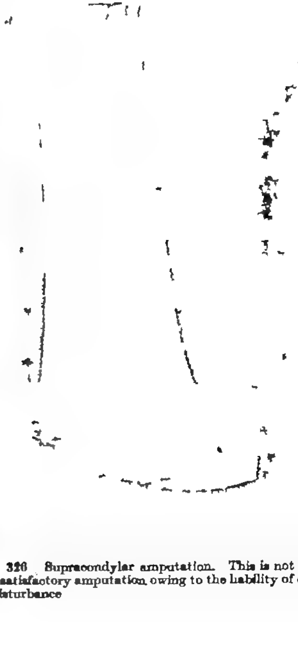

FIG 326 Supracondylar amputation. This is not considered a satisfactory amputation owing to the liability of circulatory disturbance

FIG. 323. Satisfactory above-knee amputation.

FIG. 324. Amputation through middle third of the femur. The stump became infected with gas gangrene and the gas shadows can be seen in the medial side of the thigh.

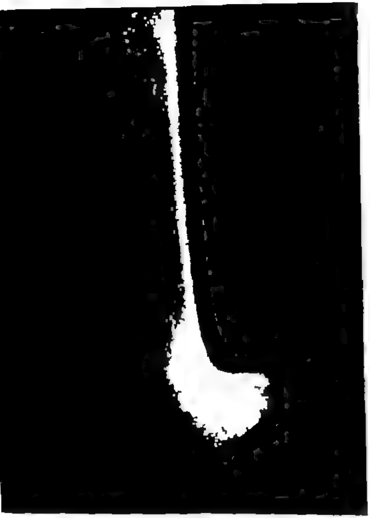

Fig 325 Stokes-Gritti amputation. The patella has fused at a considerable angle to the line of the shaft This is an unsatisfactory amputation as it is not easy to fit an end bearing prosthesis.

Fig 326 Supracondylar amputation. This is not considered a satisfactory amputation owing to the liability of circulatory disturbance.

FIG. 323. Satisfactory above-knee amputation.

FIG. 324. Amputation through middle third of the femur. The stump became infected with gas gangrene and the gas shadows can be seen in the medial side of the thigh.

Fig. 329 Genu valgum deformity of knee joint. High below knee amputation. Bony spur from lower end of both bones.

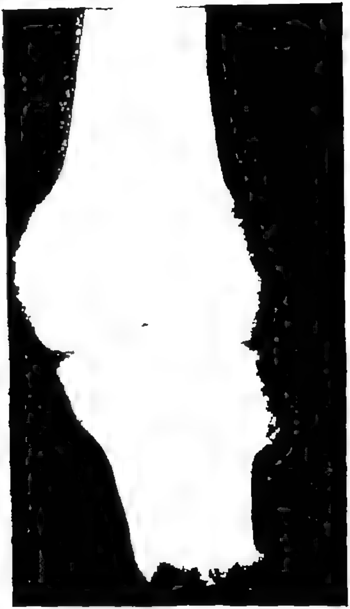

Fig. 330 High below knee amputation with spur formation on the adjacent ends of tibia and fibula. A pseudoarthrosis has occurred between them giving rise to pain and bursa formation. Surgical excision.

Fig. 327 Infection of lower end of below knee stump with marked osteoporosis. Clinically œdema of stump.

Fig. 328. Below knee amputation. The stump is of satisfactory length but no attempt has been made to bevel the lower end of the tibia, and later development of a curved bony spur from the lower end of the fibula necessitated re-amputation.

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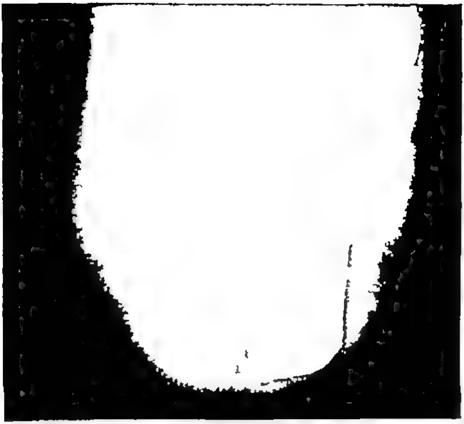

FIG 331 High below knee amputation. A very small fibula stump has been left which has been abducted by pull of muscle This is not a satisfactory amputation because the stump is both short and bulky (An indication for removal of the fibula.)

FIG 332. Short below knee amputation. Unable to tolerate artificial limb Extensive calcification in lower end of stump

Dressings. Re-dressing of the wound after amputation should be avoided as much as possible It is a good thing to apply tulle gras in the first place as this prevents the outer dressing sticking to the skin If drains are used these are removed one or two days after the operation They should have been inserted in such a way that they can be removed without the necessity of disturbing the gauze immediately in contact with the wound

A stump is not necessarily painful but it may be so and the patient always considers that an amputation stump will give him pain It is therefore absolutely essential that the nurse or doctor who handles an amputation should be gentle Otherwise the patient will immediately start associating his amputation with pain

If the patient remains free from pain there is no need to inspect the wound until the stitches are removed about the tenth day after operation The stump is usually very sensitive and the patient may find it difficult to control its movements An assistant should be at hand to steady the limb because of involuntary shaking—not pain

Fat embolism is a rare complication of amputation but it does occur The condition follows soon after amputation and may take two forms —

(1) That in which the patient becomes comatose and eventually dies , and

(2) That in which there are pulmonary signs

Petechial hæmorrhages may develop all over the body in both types especially on the chest

In the first form the patient may suddenly become comatose He breaks out in a profuse sweat is delirious but his pulse rate is good. Unless one is aware of this condition the diagnosis may prove baffling but it is clearly a cerebral catastrophe Careful nursing is required The patient s breathing should in no way be obstructed. Attention to the bladder is most important Administration of nasal oxygen gives relief

In the second form the patient has hæmoptysis and may complain of pain in the chest He should be nursed in the upright position and treated as if he had pneumonia The condition usually clears up

Sepsis may occur in a stump The patient complains of pain is febrile has difficulty in sleeping and the stump may appear red, tense and sensitive At first it should be treated with antiphlogistine after which if tension increases a few stitches over the maximum redness or tenderness may be released The evacuation of a septic hæmatoma soon helps to improve the patient s general condition and the stump drains and will eventually settle down

Antibiotics should be administered. *Sedatives* should be given immediately after operation and continued for two or three days

Back Splints. If the patient complains of pain the back splints should be loosened, and if he still continues to complain it may be that his dressings are too tight and they should be released as far as the tulle gras

Physical Treatment

The stump should lie flat on the bed and pillows which may flex the hip or knee are forbidden. The muscles controlling the joint immediately above the amputation are exercised to assist healing and prevent stiff and deformed joints (Fig 333) The patient can be sat out of bed for increasing periods from about the third post-operative day

When the stitches are removed the patient is encouraged to move his joints and this

CHAPTER XVIII

NURSING AND AFTER CARE OF AMPUTATION PATIENTS

The reward of a thing well done is to have done it

EMERSON

A PATIENT with an amputation is in many ways easy to nurse There is nothing to *inhibit full excursion of the chest and the patient can eat an ordinary diet* Special care however should be taken to avoid bedsores and attention given to the heel and outer border of the remaining foot The skin of a patient with senile gangrene will not tolerate pressure There should be an overhead rope over the bed and prior to operation the patient should be taught how to lift his buttocks off the bed.

As a rule there is very little shock after an amputation and even the older patients, with senile gangrene and diabetes stand the operation remarkably well Blood transfusion in the theatre is rarely necessary except in the case of a fore-quarter or a hind quarter amputation.

An amputation site does not bleed any more than any other operation unless the ligature slips but of course the nurse should watch for bleeding The loss of a large quantity of blood is reflected in the pallor and appearance of the patient and the nurse should detect this at once Many nurses like to have a tourniquet attached to the bed, but it is not easy to apply a tourniquet without tuition and practice Unless the rubber is stretched to its full capacity before being applied, the pressure is only sufficient to obliterate the superficial veins Tourniquets can do harm and the correct method of stopping arterial bleeding is for the surgeon to tie the artery If the dressing over a stump suddenly becomes soaked with blood the stump should be bandaged as tightly as possible and the surgeon informed at once and if he is wise he will immediately take the patient to the theatre open the wound and tie the bleeding artery

Sometimes a considerable amount of blood appears on the dressing the day after the stitches have been removed There is no need for alarm, as this represents the liquid part of a hæmatoma which has suddenly evacuated itself, and after inspection of the wound a fresh dressing is usually all that is required

(1) It is a good plan to place a cradle over the amputation stump to protect it from the weight of the bedclothes which should be arranged in such a way that the stump is exposed and any nurse or passer by can be on the look out in case of hæmorrhage taking place This will then be readily noticed and prompt action taken.

(2) Occasionally a hæmatoma forms when the stitches have held and the wound has healed. This aseptic hæmatoma will take a considerable time to absorb It is usually harmless and the diagnosis becomes clear when it is seen that the stump instead of shrinking develops an unusual fullness and is round. Palpation may reveal the presence of fluid. Stumps which exhibit this condition should be evacuated through the suture line under aseptic conditions This can be carried out by the nurse who inserts a sinus forceps through the suture line into the hæmatoma It is a harmless procedure

continuous lateral compression in such a way that the maximum force operates at the lower end and diminishes in an upwards direction This can be achieved (a) by bandaging or (b) by the wearing of a plaster pylon

(a) *Remodelling the Stump by Bandaging* For an above knee stump, two 6 in crêpe bandages are sewn end to end to make one long bandage

The bandage is tightly rolled so that sufficient tension can be gained when applying it. With the patient recumbent the free end of the bandage is laid upon the front of the

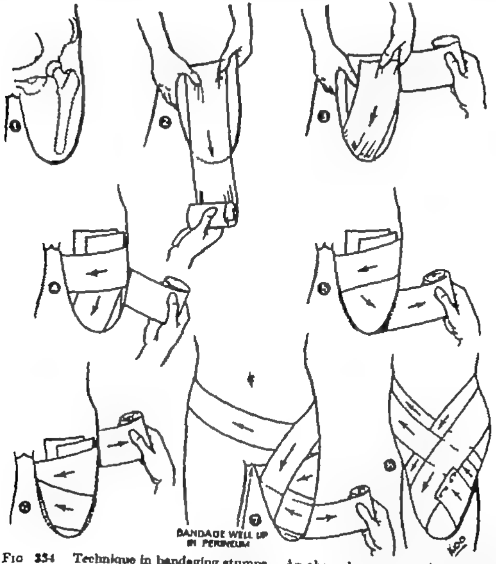

FIG 334 Technique in bandaging stumps. An above-knee stump shown here
[A. J Craft Annals of Royal College of Surgeons.

stump at the level of the inguinal ligament and held at the corners by the patient s thumbs (Fig 334) It is carried down the front of the stump over the end now held and up the back to the gluteal fold where the corners are now held by the patient s index fingers Then passing obliquely down the back the bandage is again pulled firmly over the outer angle and up the front to the middle and down again obliquely over the inner angle and up the back each fold being held by the patient s fingers and thumbs These three turns of the bandage should compress the middle and the two sides of the end of the stump A turn is now loosely taken round the top of the stump to anchor the upper ends The bandage is then continued in spica fashion from below upwards the soft tissues on each

helps to prevent the muscles becoming adherent to the skin, and improves the circulation. *Above knee stumps, particularly if short, tend to develop flexion deformities at the hip* since the flexors are relatively stronger than the extensors. In order to counteract this the patient should lie for a period of each day face downwards and, in this position, practise lifting his stump off the bed.

The team, consisting of nurse, physiotherapist and surgeon, continue their task after the amputation. Their object should be: (1) to prepare the stump for fitting with

FIG. 353. Below knee amputation with acute flexion deformity of the knee and gross scarring and invagination in front of the knee. The flexion deformity is due to poor after care. (Sitting in a chair with the stump flexed).

an artificial limb, (2) to prepare the patient physically and mentally so that he can use the amputated stump and artificial limb to the utmost value.

1. **Preparation of the Stump.** To begin with the stump is œdematous, bulky and the wrong shape, and requires remodelling from a cylinder to a cone. After an amputation the soft tissues begin to shrink and it is desirable to obtain the maximum shrinkage before measurements are taken for an artificial limb, in order to get the most accurate fit for the socket.

The conversion of a large cylindrical stump into a small conical one is achieved by

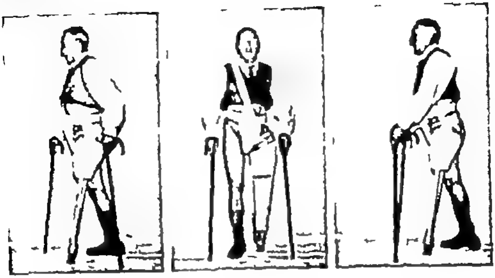

FIG 336 Left above-knee pylon—hospital constructed. Walking with sticks. Note alternating position of walking sticks.

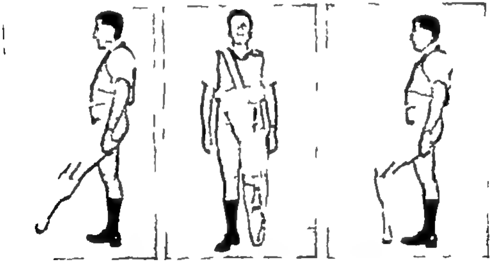

FIG 337 Below knee amputation—hospital constructed pylon. Walking with ease

same way as he is obliged to do in a disarticulation of the hip with a tilting table) and his gait is therefore ungainly or secondly the correct way namely for the patient to control his limb by his stump muscles and so produce a gait which is therefore more natural

The majority of amputees should be trained to have stump-controlled limbs but they can use them to the best advantage only if the stump muscles are developed and they have learnt to make use of those muscles and if the joints move freely

In an above knee amputation the essential muscles are the extensors and adductors and the flexors of the hip The patient should be encouraged to contract these muscles voluntarily as soon as possible after amputation and when the wound is healed he is encouraged to join classes with other amputees in the gymnasium to exercise his stump

An excellent apparatus for exercising stumps can be made by fixing a piece of wood as long as need be horizontally to the wall at a height of 3 ft from the ground. At intervals of about 3 ft pulleys are screwed to the board. A webbing sleeve 4 in deep behind and 2 in in front is passed round the stump A cord passes from the sleeve over a pulley to

turn being firmly compressed in an upward and outward direction and the bands crossing on the outer side of the leg and not on the front The bandage should be brought well up on the inner aspect of the thigh to the perineum The bandage becomes loose after

Fig. 335. A pressure sore over the tibial tubercle resulting from poor bandaging technique. This patient had vascular disease Great care is required in shaping amputation stumps in patients with vascular disease.

a few hours and its value is diminished It should, therefore be reapplied three or four times a day

For a below knee stump and for the upper limb two 4-in. bandages are used and applied in a similar fashion (Fig 334)

(b) *Remodelling the Stump by the Wearing of a Pylon* A pylon has the following advantages (1) it rapidly builds the morale of the patient (2) it shapes the stump and shrinks it, (3) it helps to teach the patient to balance (4) it improves the tone and power of the stump muscles (5) it prevents the joint immediately above the stump from becoming stiff (6) it is easily and quickly made and can be available in two to three hours, (7) it enables the patient to become ambulatory as soon as his stump has healed (Figs 336 337)

2 **Preparation of the Patient for Walking** There are two methods of using an above-knee limb Firstly the patient can swing the limb by means of his trunk muscles (in the

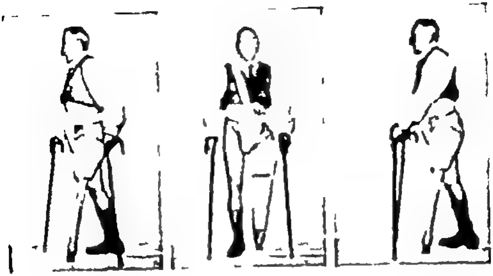

FIG. 336. Left above-knee pylon—hospital constructed. Walking with [illegible] [illegible] pattern of walking stick

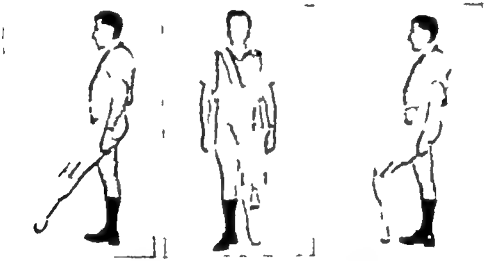

FIG. 337. Below-knee amputation—hospital constructed pylon. Walking with cane

same way as he is obliged to do in a disarticulation of the hip with a tilting table) and his gait is therefore ungainly; or secondly, the correct way, namely for the patient to control his limb by his stump muscles and so produce a gait which is therefore more natural.

The majority of amputees should be trained to have stump-controlled limbs, but they can use them to the best advantage only if the stump muscles are developed and they have learnt to make use of those muscles and if the joints move freely.

In an above-knee amputation the essential muscles are the extensors and adductors and the flexors of the hip. The patient should be encouraged to contract these muscles voluntarily as soon as possible after amputation, and when the wound is healed he is encouraged to join classes with other amputees in the gymnasium to exercise his stump.

An excellent apparatus for exercising stumps can be made by fixing a piece of wood as long as need be horizontally to the wall at a height of 3 ft. from the ground. At intervals of about 3 ft. pulleys are screwed to the board. A webbing sleeve (4 in. deep behind and 2 in. in front) is passed round the stump. A cord passes from the sleeve over a pulley to

turn being firmly compressed in an upward and outward direction and the bands crossing on the outer side of the leg and not on the front. The bandage should be brought well up on the inner aspect of the thigh to the perineum. The bandage becomes loose after

Fig 333. A pressure sore over the tibial tubercle resulting from poor bandaging technique. This patient had vascular disease. Great care is required in shaping amputation stumps in patients with vascular disease

a few hours and its value is diminished. It should therefore be reapplied three or four times a day

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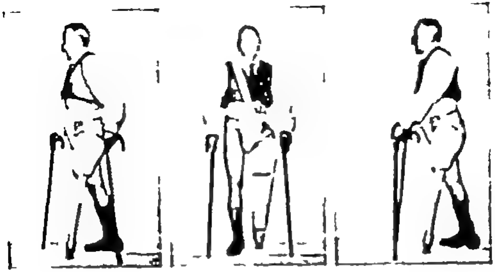

FIG. 336 Left above knee pylon—hospital constructed Walking with ... ... in form of walking stick

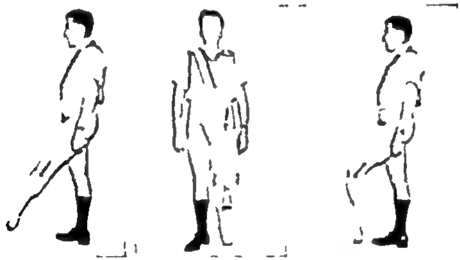

FIG. 337 Below knee amputation—hospital constructed pylon. Walking with ...

same way as he is obliged to do in a disarticulation of the hip with a tilting table) and his gait is therefore ungainly or secondly the correct way namely for the patient to control his limb by his stump muscles and so produce a gait which is therefore more natural

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a 7–14-lb sandbag The weight of the sandbag can be increased daily up to about 20 lb A movable hand rail is placed a few feet from the wall The patient faces the wall and rests his hands on the rail while he raises the sandbag off the floor by contracting his hip extensors After a few minutes the sleeve is moved round the thigh and the patient stands sideways with the sleeve nearest the wall and again raises the sandbag off the floor this time by using the adductors of the hip The same exercise is repeated for the flexors of the hip This exercise can be improvized on a chair in the ward (Fig 338)

The work is gradually intensified by increasing the speed and duration of the exercises Several patients are exercised at the same time as comradeship and the spirit of competition helps to improve not only their physical but also their mental well being

The exercises are supervised by a physiotherapist who ensures that the patients keep their trunks still and do the work with their hip muscles

Stump exercises serve three functions (1) the muscles regain their power (2) the

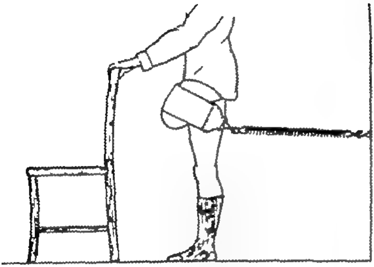

Fig 338 Stump exerciser in use

Modelling amputation stumps by elastic stump socks I have recently been adopting the method of modelling stumps post operatively by elastic stump socks. A conical well healed and durable stump can result as quickly as possible by this method, which is now superseding the method of stump bandaging

These elastic stump socks are made from two-way stretch material, specially woven to give maximum pressure at the distal end of the stump

The advantages of these elastic socks are—

1 They exert an even pressure (reduce the œdema)
2. They do not produce folds and invaginate the skin, thus leaving furrows.
3 They shape the stump in a conical manner and produce an even contour leaving a linear scar
4 The employment of these socks prevents any injury to the stump which may occur as a result of inexpert bandaging of a stump with vascular disease
5 The patient can apply and adjust the socks himself
6. They are not cumbersome require no bandaging and save the time of the physiotherapist

These stump socks are made in two types one set for above and another set for below knee amputations in three graded sizes—small medium and large.

The small below knee socks are also suitable for arms. They are easily washable are economical and can be used by the patient at night as well as by day They last for at least 18 months.

brain re-establishes its control over muscles that have been dormant and in danger of being disregarded as of no further use and (3) a *good range of movement* is rapidly restored to the joints

During the healing of the wound an above knee stump may acquire a flexion abduction deformity This is made more apparent if the patient lies face downwards and clasps his hands behind his head and while in this position raises his head shoulders and elbows

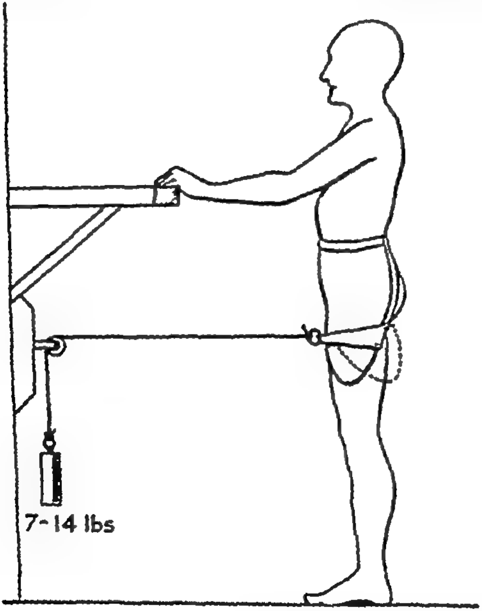

FIG 339 Simple technique for developing stump muscles in gymnasium.
(A J Croft, *Annals of Royal College of Surgeons.*

off the plinth The muscles of both hips contract by synergic action during this movement

During the course of stump exercises the flexion abduction deformity diminishes The exercises are continued daily until the stump *no longer flexes or abducts* during the test The patient is considered ready to control an artificial limb when the stump has reached a more or less stationary state from the point of view of the oedema and when his muscles are well developed and no deformity is present

The whole treatment—strengthening the muscles re-educating them and regaining mobility at the hip—takes on an average about one month

For below knee amputations the quadriceps muscle alone requires strengthening and re-educating This is done by getting the patient to raise the leg off the couch with the knee straight against resistance quadriceps drill and faradism

In an amputation of the upper limb it is of the utmost importance to obtain the fullest possible movement at the shoulder joint and the elbow joint where present and no patient should be referred for limb fitting until he has regained full mobility of these joints

3 **Teaching the Patient to use an Artificial Leg** In the course of the manufacture of a limb the patient receives several fittings, during which he uses his limb It is important that he should use the limb correctly from the beginning and one must rely on the limb-fitter to teach the patient the correct method The surgeon cannot himself superintend the instructions but he should be in a position to know what are the correct requirements as all limb fitters cannot be expected to acquire this knowledge without tuition Before attempting to walk the patient is taught three things (*a*) to stand and to balance on the limb (*b*) to swing the limb forward without abducting it and (*c*) to extend the artificial knee naturally at the end of the forward swing

To Stand and Balance on the Artificial Limb A normal person when standing on one leg maintains his balance by using his foot muscles A patient with an artificial limb has to rely on the muscles of his proximal joints and on joint sense These have to learn their new function.

The patient stands in front of a mirror and balances himself on side rails After a few attempts he is able to take his sound leg off the ground then to do so without holding the rails and finally he accomplishes this with the sound knee and hip fully flexed and the foot well clear of the ground. He should then learn to swing the limb forward without abducting it The tendency to abduction is less when the adductors have previously been developed. The patient has to learn to contract his adductors during the forward swing of the limb Walking should not be attempted until the patient can swing his limb forward without abducting it for an ungainly circumduction gait, once acquired, is difficult to eradicate

Whereas a normal person extends his knee by his quadriceps, a limb-wearer must learn to extend the artificial knee by using his hip extensors and to control it at the end of the swing by pressing his stump backwards in the socket. At the completion of the forward swing he is therefore taught to place the heel on the ground and to press backwards with his stump muscles simultaneously

Having learnt these three lessons he may start walking He is given two sticks and told to take short equal steps with both legs. The two legs should be used evenly Any sign of a limp is immediately corrected The patient on reaching this stage soon accustoms himself to his limb and learns to walk on uneven ground, on cambered surfaces and up and down hill On going upstairs he takes one step at a time, the sound leg leading On going downstairs the artificial leg goes first and the patient must remember to keep the artificial knee extended. This is rendered easier by leaning slightly forward over the limb

The learner is not allowed to look down at his feet as he walks and must rely on his hip muscles for a sense of position.

4 **Teaching the Patient to Use an Artificial Limb** All leg amputees should be

Fig 340 Short forearm amputation fitted with artificial arm and split hook. The patent is able to undertake carpentry and to adapt himself to the appliances which are most suitable for his work.

taught the knack of using their limbs and be taught to walk properly All arm amputees should also be trained for several weeks in the company of other arm amputees Observing how much can be done by others who have received their arms a week or two earlier is a great incentive to amputees The stay in hospital enables the surgeon to supply those appliances most useful to an arm amputee and most suitable to his mentality and trade As more and more dexterity is acquired the arm amputee becomes keener on doing more with the appliance he has and on learning to make use of new ones (Fig 340)

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CHAPTER XIX

ANÆSTHESIA, INCLUDING ICE ANÆSTHESIA, FOR AMPUTATIONS

> "Centuries ago Hippocrates [illegible] from general [illegible] amputation of a limb through the thigh including the [illegible] take place in eighty days; in the leg in sixty days; at the knee [illegible] days."
>
> [illegible] Taylor

Anæsthesia for amputation does not present any special problems, and the technique adopted will vary with the individual anæsthetist. The tendency at the present time is to give the patient a general anæsthetic, to obtain freedom from stimuli by the use of analgesics as pethidine, etc., and to relax the muscles as required by the use of muscle relaxants. Field blocks, spinal analgesia and refrigeration are rarely used, but have their place in a very few instances where a general anæsthetic is contra-indicated. It is the patient and not the amputation who requires the anæsthetic, and the most suitable technique for the individual will depend upon his medical condition apart from the disease which necessitates the amputation.

The co-operation of a physician and the opinion of the anæsthetist are of the utmost importance to the successful management of the case by the surgeon. When anæsthetising a patient on whom an amputation is to be performed, all that is required in the majority of cases is a light plane of general anæsthesia. The depth of anæsthesia is one which will give the patient relief from pain, prevent shock and keep him quiet. When large groups of muscles and nerves are severed the addition of analgesics and muscle relaxants will be required. Except in large ablative procedures, none of the standard amputations requires prolonged anæsthesia. Inhalation anæsthesia is certainly the method of choice and gives the best results to the patient, enabling the surgeon to accomplish his work under the best possible conditions.

Most of the accepted anæsthetic agents and pre-operative drugs serve well for the average case according to the preference of the anæsthetist. Peripheral vascular and diabetic cases in particular should be examined by the physician, while diabetic cases should be controlled for acidosis, their insulin intake regulated and stabilization ensured before operation. Advanced age and hypertension require routine examination, and individual consideration should be given to heart disease, diabetes and liver disorders; anæsthetic agents with low toxicity should be employed, i.e., those which do not interfere with hepatic or renal functions and do not alter insulin production. In arteriosclerosis and hypertension anæsthetic agents which do not unduly strain the cardiac reserve or impair circulatory function should be preferred. Chloroform and nitrous oxide on the whole are not satisfactory, since the former may cause damage to the liver, and the latter asphyxia.

A general anæsthetic is the method of choice. It reduces the patient's discomfort to a minimum and upsets his metabolism as little as possible. Sawing and removing an

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diffusely infiltrated with local an[illegible] [illegible] effective but all [illegible] shoulder region

The brachial plexus block [illegible] as a rule only the expert anaesthetist will have [illegible] of the whole limb below the [illegible] If the [illegible] additional local anaesthetic must be injected along the [illegible] nerves from the cervical plexus pass [illegible] into the anterior part of the axilla where [illegible] second intercostal space to the inner aspect of the arm [illegible] of the sympathetic fibres in the plexus [illegible] the limb Where no tourniquet is used haemorrhage can be [illegible] lines of incision with adrenaline (1 in 200,000)

Theoretically it should be possible to anaesthetize [illegible] tion but as this requires blocking some fifteen nerve [illegible]

Refrigeration Anaesthesia in Amputations

Since the earliest times local applications of cold have been used [illegible] Hippocrates recommended the application of cold for fevers and for [illegible] A century ago cold salt solutions were used to relieve pain and to retard the growth of accessible cancers Carbon dioxide snow is frequently employed for the treatment of birth marks and rodent ulcers while ethyl chloride sprays are used as local anaesthetics for minor operations The term refrigeration anaesthesia is employed for the reduction of the local temperature by cooling to [illegible] This is [illegible] when the general body temperature is reduced to about [illegible]

It was this ability to produce local anaesthesia and to prevent [illegible] led Allen and his co-workers to start this form of anaesthesia in America Later the method was adopted in this country by many surgeons In all cases reported by Allen anaesthesia has been complete and the advantages originally claimed were (a) that the patients were not exposed to the dangers of general anaesthesia and (b) that there were few post-operative complications The patients were allowed to continue taking their meals they suffered neither shock nor pain

Ottaway and Foote advocated *refrigeration anaesthesia* stating that in chilling the tissues to just above freezing point there was a reduction of absorption of toxic products bacterial growth was inhibited and the metabolism of the injured part was so reduced that even the collateral blood supply became adequate

Technique As with most problems in surgery and mechanics the simplest technique is usually the best

Apparatus (*a*) Mackintoshes *are employed to surround the limb* which is encased in finely broken up ice The mackintoshes are held in place by calico bandages

(*b*) A specially prepared wooden cabinet about 45 × 12 × 12 in lined with lead and fitted with taps to drain away the water The limb is held in position supported by a leg-shaped duralumin frame in which there are many perforations The ice surrounds the duralumin which ensheathes the leg

About 50 lb of crushed and broken *ice are required* The circular opening through which the leg passes into the cabinet is surrounded by a rubber sheet the opening being

amputated limb from the body is unnerving to the patient and unpleasant to the surgeon. A general anæsthetic is thus more suitable

Where however the patient's condition indicates that a general anæsthetic is inadvisable, the anæsthetist can then use —

(1) Field block.
(2) Nerve block.
(3) Refrigeration analgesia
(4) Epidural analgesia
(5) Spinal analgesia.

(1) Field block is useful for amputations of the fingers and toes

(2) Nerve block is suitable for amputation of the upper limb For instance a brachial plexus block will allow painless amputation at any level below the insertion of the deltoid muscle

(3) Refrigeration analgesia can also be used for amputation of the lower limbs and is specially recommended in cases of incipient gangrene since this method is reputed to retard degenerative processes by reducing tissue metabolism.

(4) Epidural analgesia can also be used for amputations of the lower limb

(5) Spinal analgesia can be employed for amputation at any level of the lower limbs. Unilateral spinal analgesia can be used

In fore-quarter and hind quarter amputations it may be necessary to add a muscle relaxant to light anæsthesia, and a blood drip should be used in both cases. For large ablative procedures like hind-quarter amputations special precautions are needed.

(*a*) The usual pre-operative injection of morphia and atropine or omnopon and scopolamine is given one to one-and-a half hours before the operation In the elderly the use of scopolamine is better avoided.

(*b*) There are many forms of general anæsthetic which serve satisfactorily for such procedures It is advisable however not to use cyclopropane because of the frequently associated capillary hæmorrhage and with such a large area exposed it makes the control of hæmorrhage all the more difficult

(*c*) Anæsthesia is best induced as in other cases with a small dose of a thiobarbiturate and an intratracheal tube may be passed after the larynx has been cocainized or after the injection of a relaxant

(*d*) Anæsthesia is then maintained by nitrous oxide and ether through the intratracheal tube

A unilateral spinal block, for hind-quarter amputations using 10 ml. of 1/1 500 light nupercaine gives good anæsthesia for this operation provided the patient is fit enough to stand it Using this technique all stimuli are cut off from the operative field The amount of general anæsthetic which is required is therefore minimized.

Amputations of fingers can be performed conveniently under local anæsthesia by means of interdigital nerve block. For amputations of the upper limb at any higher level general anæsthesia is preferable The hand being so much more intimately connected with the mind than the foot its removal constitutes an experience far too appalling for most patients to witness If however contra indications to general anæsthesia are absolute—a state of affairs becoming increasingly rare—there is a choice between two methods of local anæsthesia either brachial plexus block or cross-section infiltration. The latter method, by which a cross-section of the limb above the site of amputation is

[illegible]

Refrigeration Anaesthesia in Amputation

[illegible] ... local temperature by cooling to [illegible] when the general body temperature [illegible]

It was this ability to produce local anaesthesia [illegible] Allen and his co-workers to start this form of anaesthesia in America [illegible] the method was adopted in this country by many surgeons. In all cases [illegible] by Allen anaesthesia has been complete and the advantages originally claimed were (a) that the patients were not exposed to the dangers of general anaesthesia, and (b) that there were few post-operative complications. The patients were allowed to continue taking their meals; they suffered neither shock nor pain.

Ottaway and Foote advocated refrigeration anaesthesia, stating that in chilling the tissues to just above freezing point there was a reduction of absorption of toxic products, bacterial growth was inhibited, and the metabolism of the injured part was so reduced that even the collateral blood supply became adequate.

Technique. As with most problems in surgery and mechanics the simplest technique is usually the best.

Apparatus. (*a*) Mackintoshes are employed to surround the limb, which is encased in finely broken up ice. The mackintoshes are held in place by calico bandages.

(*b*) A specially prepared wooden cabinet about 48 × 12 × 12 in., lined with lead and fitted with tap to drain away the water. The limb is held in position, supported by a leg-shaped duralumin frame in which there are many perforations. The ice surrounds the duralumin which ensheathes the leg.

About 50 lb. of crushed and broken ice are required. The circular opening through which the leg passes into the cabinet is surrounded by a rubber sheet, the opening being

in the form of a tube which can be inflated with a pump like a bicycle pump. This serves as a tourniquet and prevents the bed being wetted by an overflow of the melted ice

Procedure. Criticism has been levelled at this method owing to a statement that infection had arisen from anaerobic organisms like *Cl welchii* but evidently this was only conjecture for Cohen took cultures and has demonstrated that no such growth existed.

To obtain sterile conditions the technique is as follows —

(1) The patient's skin must be shaved, including the pubic hair in the case of an above knee amputation, and the usual skin preparation carried out

(2) The duralumin frame must be sterilized.

(3) The limb must then be covered with sterile towels and placed inside the frame

The frame is fixed on its supports in the box so that if the tourniquet is to be used it can be applied immediately above the level at which it is proposed to amputate The lid of the cabinet is then opened and the crushed ice is carefully packed round the limb It is advisable not to inflate the tourniquet for about an hour after the ice has been placed in position The patient remains comfortably resting in bed meanwhile and is kept warm. The minimum time for which the limb should be safely refrigerated before operation varies from two to three hours It is unnecessary to give pre-operative medication, but if a patient is apprehensive and his medical condition permits he may be given morphine gr $\frac{1}{4}$ or gr $\frac{1}{6}$ (16 mgm) or any other suitable sedative He may then be transported to the operating theatre with his limb still encased in the apparatus

When the surgeon and his team have scrubbed up and got ready the limb together with the tourniquet is removed from the apparatus and the skin prepared for operation. The site selected for amputation is finally prepared There is still ample time for the operation, as good anaesthesia persists for about two hours Amputation is performed in the usual way after which the tourniquet is released and any bleeding vessels are secured The patient remains conscious throughout the operation his ears are plugged with cotton wool but when the surgeon is about to saw through the bone it is a humane action to run a tap at full pressure in order to distract the patient's attention After the amputation the limb is then dressed in the usual way and the patient returned to bed It is unnecessary to submit him to any further cooling because he does not suffer any pain, and discomfort may be relieved by further sedation if necessary

Complications. Shock does not occur the blood pressure does not alter significantly throughout the anaesthesia, operation and post-operative period This has been established by Cohen. Pulmonary complications like broncho-pneumonia do not occur unless the patient has been thoroughly wetted by ice and even then these are uncommon. Sulphonamides and penicillin may be administered prophylactically to prevent any chest or local sepsis.

This method of anaesthesia has been employed for bad risk cases with gangrene following on arteriosclerosis diabetes mellitus and epitheliomata of the leg in which the risk arising from anaesthesia would be greater than the risk of surgery owing to advanced cardiac failure auricular fibrillation or diabetic coma

There is no doubt that anaesthesia in these cases is complete but the method is cumbersome and, with modern anaesthetic agents the number of cases that require it are very few I have amputated limbs of patients over ninety years of age using cyclopropane anaesthesia without ill-effects but an anaesthetist may not always be available

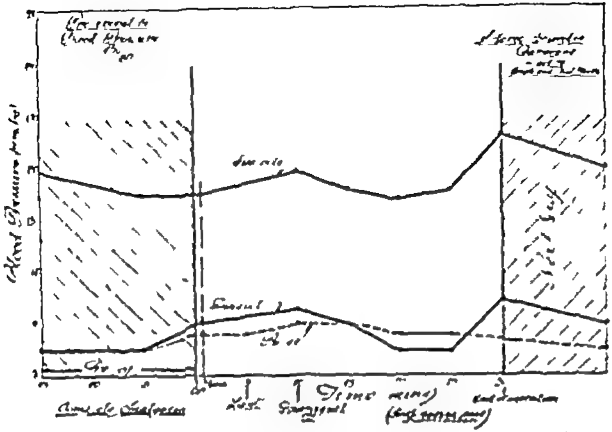

Fig. 341. Chart showing amputation under ice analgesia, blood pressure and pulse record. There was no pain on cutting the sciatic nerve. The patient slept.

or be prepared to take the risk in which case it would be possible to resort to this form of anaesthesia.

Comment. The appearance and consistency of the tissues at operation are those of chilled meat. No vascular thrombosis has been noted and sections of the larger vessels show no microscopic changes that could be attributed to refrigeration. The wound heals well and those that do not heal by first intention are no different from wounds following similar amputations with general anaesthesia in debilitated patients.

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This method of anæsthesia has been employed for bad risk cases with gangrene following on arteriosclerosis diabetes mellitus and epitheliomata of the leg in which the risk arising from anæsthesia would be greater than the risk of surgery owing to advanced cardiac failure auricular fibrillation or diabetic coma

There is no doubt that anæsthesia in these cases is complete but the method is cumbersome and, with modern anæsthetic agents the number of cases that require it are very few I have amputated limbs of patients over ninety years of age using cyclopropane anæsthesia without ill-effects but an anæsthetist may not always be available

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CHAPTER XX

AMPUTATIONS UNDER UNUSUAL CIRCUMSTANCES

Haste is needful in a desperate case "
SHAKESPEARE

BESIDES the amputations carried out under optimum conditions there are a variety of occasions when urgency demands amputations without the benefit of the facilities that one would normally wish to have

The first of these is amputation in the field The experience gained in the last two World Wars has improved enormously our technique and our knowledge of the type of amputations most likely to give satisfactory end results There still remains diversity of opinion on the basic ideas for emergency amputations American surgeons favour the guillotine amputation, and Major-General Kirk, U S Surgeon-General, and his colleague McKeever maintain that free drainage is best secured by this procedure and that it is length preserving British surgical opinion, however has tended to oppose guillotine amputation for the following main reasons —

(1) The skin tends to retract leaving a conical raw area with a projecting bone at the end unless skin traction is maintained continuously

(2) The patient due to jolting to his raw stump suffers considerable pain and great anxiety in his travels to the base area

(3) As a corollary to skin retraction there is of course the greater danger of secondary infection, since a larger area of the flesh surface is left uncovered.

Nightingale in 1944 condemned the use of the guillotine amputation He used a technique which has again found considerable favour i e that of approximating two flaps over a gauze pad, secured by two sutures

Mitchell, Logie and Handley writing of their experiences in desert warfare during the Wavell campaign said that guillotine amputees arriving at the base were for the most part desperately ill men Secondary infection was an invariable sequel, the patients were in considerable pain and loss of serum was a pronounced feature In my opinion, guillotine or flapless amputations should be avoided, as there is no time saved by this procedure and the greatest time spent in amputation is in securing hæmostasis. It does not provide better drainage than a flap amputation with the flap left open it does leave a raw painful, conical, granulating surface which can rarely be covered by skin traction.

In the Middle East the technique employed by Nightingale was often used the flaps were anchored back over a gauze roll and impregnated with an antibiotic and two or three stitches were used to fix the flaps

Whilst more certain control of infection has proved of immense value in surgical procedure one should not alter the technique for this reason alone It should not be assumed that penicillin and other means which we now have at our disposal for controlling infection, has in any way changed the essential picture

Although a great deal of research has been done at Roehampton to determine a technique for operating in an emergency which would secure as good a stump as possible with one operation, experience has shown that a second operation done at leisure with the object of securing the best possible stump for limb fitting is the more desirable Experience has also taught us that the emotional disadvantage of a man undergoing two operations is outweighed by the physical advantage of a satisfactory stump In the 'field, therefore it should be a maxim to bear in mind that the limb should be removed at the lowest possible level compatible with the trauma to permit subsequent surgery to be performed in consultation with the limb fitting surgeon for the eventual satisfactory use of the prosthesis

Spontaneous Amputation

Spontaneous amputation in cases of arteriosclerosis is not a common occurrence these days Due to the improved methods of early diagnosis and palliative treatment retrogression of the disease is rarely permitted to reach the stage at which separation occurs However the odd case still occurs and the typical picture is as follows —

The patient is usually very old and has been confined to bed for a long time He first complains of coldness of the toes combined with pain, tingling and numbness—conditions which have had a slow and insidious onset The great toe is the usual site for the primary appearance of gangrene The process gradually involves the whole of the foot, and a demarcation line is unusual When the ankles are involved however a defined demarcation normally appears the forepart becoming œdematous unhealthy with an offensive odour and going through a variety of colouring before it finally becomes black, shrivelled cold and lifeless Separation is complete in about ten days after the appearance of the demarcation line and for a while there might even appear some improvement in the general condition of the now usually moribund patient This is however likely to be only a temporary improvement The process is inevitably retrogressive with further degeneration of the tissue which may ultimately involve most of the leg

Amputation in Bed

With all the facilities of modern aseptic surgery pre-operative preparations and anti-shock treatment (procedures which are necessarily of a first aid nature) indications for amputation in the patient s bed are naturally few It is limited to most unusual circumstances and is not to be advocated However under the circumstances of a modern industrial and mechanical age the necessity for prompt life-saving amputation does occur Indications may be divided into —

(1) Severe compound fracture or crushed limbs that cannot survive due to interference with circulation

(2) Infection by anaerobic organisms with spreading gangrene

(3) Laceration or crushing of soft parts to such an extent that (*a*) the presence of the limb is retarding recovery from or accentuating shock and (*b*) subsequent scarring will leave a useless limb

In these cases it is of vital importance to choose the right moment to amputate Equally important is the performance of the operation accompanied by the least possible disturbance to the patient for the thin thread of life may easily be upset by the temporary suspension of blood transfusion necessitated by the transference of the patient from bed

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engraving by van der Gucht, showing the patient and the amputated arm together with the mill in which the incident occurred The miller, Samuel Wood had his right arm torn off in 1737 while working in the mill Cheselden notes that there was very little bleeding because the arteries were stretched The patient had no severe symptoms and was cured by superficial dressings only

Punitive Amputation

The practice of amputating the offending hand or hands of robbers is still carried out amongst certain primitive peoples even to day and many instances are recorded of the practice in more civilized countries until comparatively recent times It would seem that the common practice was to place the hand or hands on a block whilst the " surgeon executioner " performed amputation by one fell blow of a large sharp sword at or near the articulation of the wrist

Negroes in the Congo and Indians in Brazil have had their hands lopped off if they collected insufficient wild rubber '

Self-amputation

Cases have been recorded of persons amputating their own limbs usually a foot leg or hand to extricate a crushed member from under fallen masonry or a mangled and useless limb from a machine under circumstances where no trained or even untrained assistance was possible and usually when the amount of tissue to be severed was nominal and of a soft nature Fingers have been chopped off by the owners when bitten by a poisonous snake

Cases have also been reported in the East where itinerant beggars in order to arouse sympathy have by a process of gradually tightened cords severed one or both of their feet These interesting articles were then tied by string around their necks and used as an additional incentive to extricate charity from passers by Two such mummified feet are on view in the Museum of the Royal College of Surgeons of England. They were purchased from a footless Chinese beggar and sent to the Museum

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to operating theatre or even the minimal shock caused by the movement of the patient from the bed to the operating trolley and from the trolley to the theatre table

Occasionally it is impossible or at best extremely difficult to restart blood transfusions after interruption during transport, so it will be appreciated that in certain circumstances of multiple injuries transport to the normal and desirable condition of theatre amputations may not always be possible The ideal if possible would be to wheel the bed accompanied by the transfusion apparatus directly to the theatre so that at least the facilities of the normal place of operation may be available Such emergencies do occur and surgeons desiring to have a comprehensive knowledge of amputation, should be cognizant of them.

The procedure is as follows —

(1) Anæsthetic if given should be of intravenous pentothal or cyclopropane (2) speed is essential in these operations (3) the guillotine operation is the method of choice in such severely shocked patients (4) the tourniquet is applied and kept in position by an assistant who twists it round and maintains it in position manually Another assistant lifts the limb by the foot (5) mackintoshes and towels are quickly applied (6) incision is begun on the posteromedial aspect of the limb continued over the front of the circumference and carried down to the bone which is quickly divided with a saw (7) skin is retracted as far as possible by pressure with the free hand (8) femoral vessels are clamped and tied with suitable suture (9) the first assistant then releases the tourniquet slightly and any strongly bleeding vessel is clamped and ligatured whilst the generalized ooze is ignored (10) the tourniquet is now held tightly again (11) a local antibiotic is applied to the stump area (12) tulle gras is then applied and the stump is firmly bandaged (13) a firm plaster strapping is then fixed over the whole anchored from the stump to the abdomen in front and to the buttocks behind and from the inner side to the outer aspect of the thigh.

FIG 34* A traumatic amputation illustrated by an engraving by Van der Gucht showing the patient and the amputated arm together with the mill in which the accident happened. The miller Samuel Wood, had his right arm torn off in 1737 while working in the mill. Cheselden notes that there was very little bleeding because the arteries were stretched. The patient had no severe symptoms and was cured by superficial dressings only

By courtesy of British Medical Journal, from Cheselden W "Anatomy of the Human Body" 7th edition, 1756.

Traumatic Amputations

The wide field of emergency associated with traumatic operations presents little opportunity for hard and fast rules of procedures to be laid down In the varied circumstances these must be determined by the requirements of the individual case and with the use and modification of generally accepted principles

An interesting historical sidelight on traumatic amputation is provided by a reference in Cheselden's "The Anatomy of the Human Body" seventh edition p 321 which was published in 1756 Herein is described a case which is illustrated by a delightful

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